Agricultural Technical Cooperation Working Group

Subgroup on Sustainable Agriculture and Related Environmental Issues

The 3rd APEC Workshop on Sustainable Agricultural Development

November 16th-22nd, 2003, Chinese Taipei

Venue: ARI, Wufeng, Taichung

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The 3rd APEC Workshop on Sustainable Agricultural Development

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The 3rd APEC Workshop on Sustainable Agricultural Development

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The 3rd APEC Workshop on Sustainable Agricultural Development

Preface

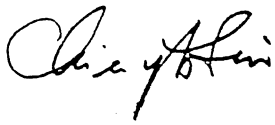
Preface

Utilization of natural resources and scientific technology applied on many sectors of industry, business, and agriculture has greatly raised our living standard. We have been well enjoyed the conveniences of our living contributed to modern technology improvements. The advancement of modern agriculture technology is ever changing and creates favorable environment to crop production. However, technological conveniences concomitantly also bring out some adverse impacts on environment, such as air, water pollution, as well as severe damages to natural ecological system. Currently, strategies of agricultural management and development adopted worldwide are directed toward sustainable development. This new trend is to keep agricultural production not only to increase farmers' income but also maintain a sound environmental ecology. The aims of sustainable agriculture should focus not only on promoting agricultural production but also on emphasizing ecological preservation and rational use of natural resources. Therefore, the connotation and priorities of sustainable agriculture should include and place on: A. Preserving the natural ecological resources. B. Maintaining the soil productivity. C. Encouraging crop rotation. D. Appropriate weeding and pest control. In addition to producing good quality produces. We are not to stay and stick to the management for the concept of pursuing yield only, but also we should endeavor our effort to forward the sustainable agricultural development.

After many years' practices and validation, practical experiences and innovated technologies have been developed in many unities of APEC members. With a view to boost sustainable agricultural development in the Asian Pacific region by strengthening cooperation and sharing information and expertise on relevant technologies, the Council of Agriculture (COA) of Chinese Taipei organized the 3rd APEC workshop on Sustainable Agricultural Development held at ARI, COA, Chinese Taipei in November 2003. A lot of valuable and inspired papers are presented in the workshop concerning sustainable crop production technology came out of five sessions: (1) plant breeding and cropping system; (2) water management; (3) soil fertility management and recycling of agricultural wastes; (4) pest management; and (5) education & extension. Many wonderful introductions of current status and future sustainable

agricultural development among members of APEC economies are also reported. With such a fruitful outcome, speeches and reports of participators are edited and published to attain the goals of encouraging cooperation among APEC member economies on developing sustainable crop production technology for promoting sustainable agricultural development; gathering information and share expertise and experience on conventional and innovative sustainable crop production technologies among APEC member economies; and benefiting future joint activities for member economies to promote sustainable agriculture.

Chien-Yih Lin, Ph.D.



Director General
Agricultural Research Institute
Council of Agriculture, Chinese Taipei

The 3rd APEC Workshop on Sustainable Agricultural Development

Meeting Information

The 3rd APEC Workshop on Sustainable Agricultural Development

November 16th - 22nd, 2003
Agricultural Research Institute, Council of Agriculture, Chinese Taipei

Background

Sustainable agricultural development is the foundation of the sustainable development of human society and economy. It is one of the keys to boost rural economy, sustainable stable social development, and to protect ecological environment through rational use of resources. Along with a long period of practices, many APEC economies have developed abundant technologies for sustainable agriculture and accumulated lots of experiences of their applications, to name a few, such as inter-cropping, intensive agricultural technologies and ecological agricultural technologies, which are all deserved to be introduced and shared among APEC economies.

So far two APEC workshops on sustainable agriculture and related environmental issues have been held by the Philippines (2001) and P.R.China (2002), respectively. These activities had successfully disseminated the useful information on sustainable agricultural development to APEC member economies. In order to further promote sustainable agricultural development in the region by strengthening cooperation and sharing information and expertise on relevant technologies (both conventional and innovative), the Council of Agriculture (COA) of Chinese Taipei proposes to host the 3rd workshop on Sustainable Agricultural Development in November 2003. The main theme of the workshop will be "sustainable crop production technology" which includes five topics: (1) plant breeding and cropping system; (2) water management; (3) soil fertility management and recycling of agricultural wastes; (4) pest management; and (5) education & extension.

Objectives

The objectives of this workshop are listed as follows:

- To encourage cooperation among APEC member economies on developing sustainable crop production technology for promoting sustainable agricultural development;
- To gather information and share expertise and experience on conventional and innovative sustainable crop production technologies among APEC member economies; and
- To formulate future joint activities for member economies to promote sustainable agriculture.

The 3rd APEC Workshop on Sustainable Agricultural Development

Inaugural Session

The 3rd APEC Workshop on Sustainable Agricultural Development

Agenda

The 3rd APEC Workshop on Sustainable Agricultural Development

November 16th - 22nd, 2003

Agricultural Research Institute, Council of Agriculture, Chinese Taipei

Program

Date, Time & Activity		Location
Sunday, November 16		
08:00-23:00	**Arrival (CKS International Airport & Bus Southbound to Splendor Taichung Hotel)**	
19:00-21:00	**Reception**	12th Fl. Splendor Taichung Hotel
Monday, November 17		
08:10-8:50	Bus from Splendor Taichung Hotel to Agricultural Research Institute (ARI), COA	Main Entrance, Splendor Hotel
08:30-09:30	**Registration**	International Conference Hall, 3rd Fl. Horticultural Building, ARI
09:30-10:10	**Opening Ceremony** Chairperson: Mr. Ming-Lai Wang (Director-general, International Cooperation Department, Council of Agriculture) Mr. Ming-Lai Wang (Director-general, International Cooperation Department, COA, *Chinese Taipei*) Dr. Chien-Yih Lin (Director-general, Agricultural Research Institute, COA, *Chinese Taipei*)	
10:10-10:50	**Photo & Coffee Break**	
10:50-12:00	**Session 1 — Keynote Speech** Chairperson: Dr. Bing-Huei Chen (Deputy Director-general, Agricultural Research Institute, COA, *Chinese Taipei*) **Current Status and Future of Sustainable Agricultural Development** Dr. Kazutake Kyuma (Professor Emeritus, Kyoto University, *Japan*)	International Conference Hall, 3rd Fl. Horticultural Building, ARI
12:00-13:30	**Lunch** (Buffet)	Training Center, ARI

Date, Time & Activity		Location
Monday, November 17		
13:30-15:30	**Session 2—Plant Breeding and Water Management** Chairperson: Dr. Te-Yeh Ku (Former Lead Shepherd, ATCWG, APEC)	Conference Room, 1st Fl. Technical Service Building, ARI
13:30-14:30	**Plant Breeding:** **Strategy to Increase Maize Productivity While Reducing Nitrate Contamination to the Environment** Dr. Chia-Yin Tsai (Professor Emeritus, National Taiwan University, *Chinese Taipei*)	
14:30-15:30	**Water management:** **Rotational Cropping Pattern and Irrigation Prevailed in Taiwan** Dr. Hai-Sheng Ko (Research Scientist, Agricultural Engineering Research Center, *Chinese Taipei*)	
15:30-16:00	**Coffee Break**	
16:00-17:00	**Economy Report & Roundtable Discussion among APEC Member Economies** (Delegates and Invited Speakers only) Chairperson: Mr. Ming-Lai Wang (Director-general, International Cooperation Department, COA, *Chinese Taipei*) ● Integrated Agri-disaster Management for Sustainable Agricultural Development in China Mr.Youqi Chen (Professor, Institute of Natural Resources and Regional Planning, CAAS, *China*) ● Mr. Somporn Isaranurak (Senior Expert, Department of Agriculture, *Thailand*) ● Mr. Teng Tay Yeo, Head of Station, Department of Agriculture, *Malaysia*) ● Mr. Vele Kagena (Director, Department of Agriculture & Livestock, *Papua New Guinea)*	
17:00-17:40	Bus from ARI to Splendor Taichung Hotel	Entrance, Training Center
18:20-18:25	Bus from Splendor Taichung Hotel to Hotel National Taichung	Main Entrance, Splendor Hotel

18:30-21:00	**Welcome Dinner Hosted by COA, Chinese Taipei**	Hotel National Taichung
Date, Time & Activity		**Location**
Tuesday, November 18		
07:45-08:25	Bus from Splendor Taichung Hotel to ARI	Main Entrance, Splendor Hotel
08:30-09:30	**Session 3—Cropping System** Chairperson: Dr. Kazutake Kyuma (Professor Emeritus, Kyoto University, *Japan*) **Multiple Cropping as a Strategy in Sustainable Soil Management** Dr. Shan-Ney Huang (Director-general, Agriculture & Food Department, COA, *Chinese Taipei*)	Conference Room, 1st Fl. Technical Service Building, ARI
09:30-12:00	**Session 4—Soil Fertility Management and Recycling of Agricultural Wastes** Chairperson: Dr. Chia-Yin Tsai (Professor Emeritus, National Taiwan University, *Chinese Taipei*)	
09:30-10:30	**Soil Fertility Management: Nitrate Contamination of Groundwater and Soil Management** Dr. Morihiro Maeda (Senior Researcher, National Agricultural Research Center, *Japan*)	
10:30-11:00	**Coffee Break**	
11:00-12:00	**Recycling of Agricultural Wastes: Biological Treatment Technology for Recycling Agricultural Wastes for Sustainable Agriculture and Environmental Protection** Dr. Ping-Yi Yang (Professor, Dept. of Molecular Biosciences and Bioengineering, University of Hawaii, *USA*)	
12:00-13:30	**Lunch (Buffet)**	Training Center, ARI
13:30-15:30	**Session 5—Pest Management** Chairperson: Mr. Denis Hamilton (Pesticide Chemist, Dept. of Primary Industries, Animal & Plant Health Service, *Australia*)	Conference Room, 1st Fl. Technical Service Building, ARI
13:30-14:30	**Pest Control: Managing Plant Diseases without Using Pesticides in Sustainable Agriculture** Dr. Wen-Hsiung Ko (Professor, Dept. of Plant Pathology, University of Hawaii, *USA*)	

14:30-15:30	**Sustainable Management of Insect-Borne Fungal Plant Diseases: A Case Study in Canada** Dr. Henry H.C. Huang (Principal Research Scientist, Lethbridge Research Centre, *Canada*)	
Date, Time & Activity		**Location**
Tuesday, November 18		
15:30-16:00	**Coffee Break**	
16:00-18:00	**Session 5—Pest Management (continued)** Chairperson: Dr. Wen-Hsiung Ko (Professor, Dept. of Plant Pathology, University of Hawaii, *USA*)	Conference Room, 1st Fl. Technical Service Building, ARI
16:00-17:00	**Management of Pesticide Residue: Safety Evaluation and Regulatory Control of Pesticide Residues in Chinese Taipei** Dr. Gwo-Chen Li (Director-general, Taiwan Agricultural Chemicals and Toxic Substances Research Institute, COA *Chinese Taipei*)	
17:00-18:00	**Management of Pesticide Residues in Sustainable Agriculture** Mr. Denis Hamilton (Pesticide Chemist, Dept. of Primary Industries, Animal & Plant Health Service, *Australia*)	
18:10-	Bus from ARI to Splendor Taichung Hotel	Entrance, Training Center
Wednesday, November 19		
07:45-08:25	Bus from Splendor Taichung Hotel to ARI	Main Entrance, Splendor Hotel
08:30-09:30	**Session 6—Education & Extension in Sustainable Agriculture** Chairperson: Dr. Henry H. C. Huang (Research Scientist, Lethbridge Research Centre, *Canada*)	Conference Room, 1st Fl. Technical Service Building, ARI
	Education and Extension Systems in the United State and Chinese Taipei Dr. Po-Yung Lai (Professor and Director, Institute of Tropical Agriculture and International Cooperation, National University of Science and Technology, *Chinese Taipei*)	
09:30-10:30	**Economy Report & Roundtable Discussion among APEC Member Economies** (Delegates and Invited Speakers only) Chairperson: Mr. Ming-Lai Wang (Director-general,	

International Cooperation Department, COA, *Chinese Taipei*)

- Sustainable Development of Agricultural water in Chinese Taipei
  Mr. Yi-Fong Ho (Specialist, Irrigation and Engineering Division, Forestry Department, COA, *Chinese Taipei*)
- Soil Fertility Management for Sustainable Agriculture in Chinese Taipei
  Dr. Chong-Ho Wang (Specialist, Agricultural Chemistry Division, ARI, COA, *Chinese Taipei*)
- Dr. Rogelio Concepcion (Director, Bureau of Soils and Water Management, DOA, *Philippines)*
- Mr. Valery Popovtsev (Head of Division, Ministry of Agriculture, *Russian*)

Date, Time & Wednesday,	**Activity** November 19	Location
10:30-11:00	**Coffee Break**	
11:00-12:00	**Economy Report & Roundtable Discussion among APEC Member Economies** (Delegates and Invited Speakers only) Chairperson: Mr. Ming-Lai Wang (Director-general, International Cooperation Department, COA, *Chinese Taipei*) ● Non-pesticide Methods for Controlling Plant Diseases and Insect Pests in Chinese Taipei Dr. Tze-Chung Huang (Deputy Director, Keelung Branch Office, BAPHIQ, *Chinese Taipe*i) ● Status of Greenhouse Insect Pest Biological Control in Korea Mr. Hyun Gwan Goh (Senior Scientist, Rural Development Administration, *Korea*) ● Quality Management and Good Agricultural Practices Ms. María del Pilar Coral Cordero (Specialist, Agricultural Ministry, *Perú*)	
12:00-13:30	**Lunch (Buffet)**	Training Center, ARI Conference Room, 1st Fl. Technical Service
13:30-15:30	**Overall Discussion & Conclusion** Chairperson: Mr. Joe-San Lee (Chief, International Organization Division, International Cooperation Department, COA,	

	Chinese Taipei)	Building, ARI
15:30-16:00	Coffee Break	
16:00-17:30	**Overall Discussion & Conclusion (continued)** Chairperson: Mr. Joe-San Lee (Chief, International Organization Division, International Cooperation Department, COA, *Chinese Taipei*)	
17:40-	Bus from ARI to Splendor Taichung Hotel	Entrance, Training Center

Date, Time & Activity

Thursday, November 20

Field Trip I (Dr. Hsin-Der Shih & Dr. C. C. Chen)

07:45-08:25 Bus from Splendor Hotel to ARI
08:30-09:30 Visit Agricultural Research Institute, COA (Briefing and Exhibition room)
10:00-11:00 Visit SunRise Biotech. Co.
11:30-12:20 Visit Mushroom Museum in Wu-feng Farmer's Association
12:20-13:10 Lunch (prepared by Wu-feng Farmer's Association)
14:00-15:30 Visit Yu-Chih Branch Station, Tea Research and Extension Station, COA
16:00-17:00 Visit Taiwan First Seedling CO. LTD
17:00-18:00 Dinner at the Restaurant of Taiwan First Seedling CO. LTD
18:00-19:00 Bus back to Splendor Taichung Hotel

Friday, November 21

Field Trip II (Dr. Chaur-Tsuen Lo & Dr. Hsin-Der Shih)

08:00-10:00 Bus from splendor Hotel to Mailiao, Yunlin
10:00-12:00 Visit Formosa Plastics Group Industrial Park, Mailiao
12:00-13:00 Lunch at the Restaurant of Mailiao Factory, FPG
14:00-15:00 Visit Han-Kuan Fruits & Vegetables Production Cooperative at Shi-Lo, Yunlin
15:30-16:30 Visit Flower Nursery at Tainwei, Changhwa
16:30-17:30 Bus back to Splendor Taichung Hotel
18:20-18:25 Bus from Splendor Taichung Hotel to Hotel National Taichung
18:30-21:00 Farewell Banquet Hosted by ARI, COA

Saturday, November 22

Departure

The 3rd APEC Workshop on Sustainable Agricultural Development

Opening and Welcome Address

The 3rd APEC Workshop on Sustainable Agricultural Development

November 16-22, 2003, Chinese Taipei

Welcome Address

By

Mr. Ming-lai Wang
Director General
International Cooperation Department
Council of Agriculture, Chinese Taipei

Honorable Dr. Sei-K Oh, Lead Shepherd of Agricultural Technical Cooperation Department, Dr. Bing-Huei Chen, Deputy Director of Agricultural Research Institute, honorable Keynote speaker, Dr. Kyuma, distinguished speakers and delegates, Ladies and Gentlemen:

On behalf of the Council of Agriculture, Chinese Taipei, I would like to extend my sincere welcome to all of you to participate in the meaningful activity of the 3rd APEC Workshop on Sustainable Agricultural Development, and I'm very grateful for ARI with all the support and cooperation in organizing this workshop.

As we all know, utilization of natural resources and scientific technology applied on many sectors of industry, business, and agriculture have greatly raised our living standard. The advancement of modern agriculture technology is ever changing and creates favorable environment to crop production. However, technological conveniences concomitantly also bring out some adverse impacts on environment, such as air, water pollution, as well as severe damages to natural ecological system.

Currently, strategies of agricultural management and development adopted worldwide are directed toward sustainable development. This new trend is to keep agricultural production not only to increase farmers' income but also maintain a sound environmental ecology. Modern agriculture is mechanized and uses a large amount of chemical synthetics like fertilizers, pesticides, and herbicides to increase yield and reduce cost to cope with the demand of the growing population. Nevertheless, over use of chemicals cause the deterioration of the qualities of products and environment.

It is clear that sustainable development is a new trend for agriculture management all over the world; it should be focused on pursuing sustainable use of agricultural resources as well as coordinating agriculture and environment to preserve natural ecology. Therefore, the connotation and priorities of sustainable agriculture should include and place on: A. Maintaining the natural ecological resources. B. Maintaining the soil productivity. C. Encouraging crop rotation. D. Appropriate weeding and pest control. In addition to producing good quality produces. We are not to stay and stick to the management concept of pursuing yield only, but also we should endeavor our effort to forward the sustainable agricultural development.

Throughout the world, more and more people are aware of the importance of sustainable agricultural development and also recognize the challenge we faced. In this regard, let us be ambitious to disseminate and extend ideas and concepts of sustainable agricultural development that the health of our natural resource be well nursed. I hope that all the participants attending this workshop will utilize this unique opportunity to deliberate not only on the core concepts but also practical issues and problems faced during the process of protecting their own agricultural productivity. I firmly believe that through your active participation and contribution, experience exchanging and expertise sharing, this workshop will benefit the future agriculture development for all APEC economies.

On behalf of the COA, I once again want to express my gratitude to the resource speakers both local and from abroad who will be delivering papers in the next few days and to the governments of participating economies for nominating their representation to attend this workshop.

Finally, I wish the meeting have a fruitful result and all the delegates from aboard enjoy their stay in Taiwan.

Thank you.

The 3rd APEC Workshop on Sustainable Agricultural Development
November 16-22, 2003, ARI, Chinese Taipei

Opening Remarks

By

Dr. Chien-Yih Lih
Director-general
Agricultural Research Institute
Council of Agriculture, Chinese Taipei

Mr. Chairman, honorable distinguished guests, invited speakers, delegates, and ladies and gentlemen:

As the host organizer, It is my great honor to welcome all of you at the opening ceremony of The 3rd APEC Workshop on Sustainable Agricultural Development held at ARI, COA, Chinese Taipei. We humen being have been well enjoyed the conveniences of our living contributed to modern technology improvements. However, inappropriate uses of natural resource such as over-use of chemical fertilizers and pesticides for crop production have greatly resulted in adverse effects on environment. With a view to boost environmental friendly crop production, researches concerning sustainable agriculture management have been prevailingly highlighted all over the world.

Agricultural development no doubt is closely related to human civilization , therefore, as the foundation of sustainable development of human society, the aims of sustainable agriculture should focus not only on promoting agricultural production but also on emphasizing ecological preservation and rational use of natural resources. Major components attributed to sustainable agricultural development including recycling of agricultural wastes, survey of land resources, soil conservation, diagnosis and fertilization recommendation, comprehensive pest management, effective cropping system and cultivation, and application and development of organic farming, which can ensure an ideal sustainable environment for our offspring.

Furthermore, it is imperative to apply modern technology for agricultural production to maintain balance of supply and demand of resources and better interactions between human being and environment, to attain sustainable development of human being. After many years' operation and validation, practical experiences and innovated technologies have been developed in many unities of APEC members. Therefore, it is really a good opportunity to share and exchange your experience and expertise in this workshop. I wish the fruitful outcome would greatly contribute to sustainable agricultural development in the entire Asian- Pacific region.

In closing my remarks, I encourage and expect more in detail discussions on how to cherish our agricultural resources and land for better tomorrow for our future generation. Let us work hard together! Thank you for your participation and wish you have a very successful and fruitful meeting and a pleasant stay in Taiwan.

Thank you!

The 3rd APEC Workshop on Sustainable Agricultural Development

Session 1

Keynote Speech

The 3rd APEC Workshop on Sustainable Agricultural Development
16th to 22nd November 2003, Chinese Taipei

Current Status and Future of Sustainable Agricultural Development

Kyuma, Kazutake

Professor Emeritus of Kyoto University and University of Shiga Prefecture, *Japan*

Current Status and Future of Sustainable Agricultural Development

Kyuma, Kazutake

Professor Emeritus of Kyoto University and University of Shiga Prefecture

Abstract

Sustainability is the prime requirement for agriculture, as it is an essential means for humankind to secure their food to survive. Until the dawn of the 20th century agriculture throughout the world had been basically sustainable. Animal-based mixed farming with crop rotational systems sustained the civilization of the western world. Thorough recycling of nutrient resources in rice-based crop production system in the East Asian countries was another example of sustainable agriculture. Even shifting cultivation was quite sustainable with a long natural fallow enough to replenish soil fertility. In this way agriculture did not disrupt the environment significantly and conformed to the order of the nature.

As crop yields increased, external inputs had to be introduced. Thus, besides manures some simple natural preparations like niter and guano began to be used in Europe already in the mid-19th century, but it was only after the middle of the 20th century, when a large amount of chemical fertilizers began to be used.

Introduction of powerful farm machinery in the turn of the 19th to 20th century was another momentum towards agricultural innovation in the United States. Draft animals lost their roles in a farm and fodder crops were eliminated from the crop rotation. Animal husbandry was separated from the farms specialized in food crop cultivation. Pursuit of efficiency and scale merits in the farm operation tended to force the farmers to take the path to monoculture. This tendency had become more and more prevalent in the latter half of the 20th century. All the agricultural technologies were mobilized to push up labor and land productivity in commercialized monoculture system. Ample use of chemical fertilizers and synthetic pesticides helped to suppress stresses caused by monoculture. Government farm policies and social as well as economic facilities were also geared to encourage monoculture system to attain high productivity. Agriculture in the EU countries followed almost the same path in the years after the World War II.

In Japan, the farm size was much smaller as compared to the U.S. and EU countries, but the general direction of changes after 1950 was similar and as a result use of chemical preparations became excessive and recycling of organic wastes was almost totally abolished.

In many developing countries it had been increasingly obvious towards the

end of the 20th century that the fallow period was shortened in the traditional shifting cultivation due to an increase in population pressure and legal controls imposed on the land use. In some cases shifting cultivation ceased to be the means of subsistence but became an operation for commercial crop production without an adequate means for nutrient replenishment, resulting in rapid deterioration of sustainability of the system.

All these changes that occurred in agriculture after 1950 have weakened intrinsic sustainability of agriculture and enhanced its negative impacts on the environment, such as soil erosion and degradation, water and soil pollution, and even health hazards to the people through the food and water. As such undesirable effects had become obvious, the people and the governments in developed countries gradually came to recognize the environmental hazards of the modern high-input agriculture.

In the U.S. and EU countries, the timing of recognition of the adverse effects induced by intensive agriculture coincided with that of the economic stress caused by the overproduction of cereals in the early 1980s. This became the opportunity to direct the public concerns to the restoration of sustainability in agriculture. The USDA's Program of Low Input Sustainable Agriculture (LISA) started in 1988 as an implementation of the 1985 Farm Bills. In EU (formerly EC), too, policies to encourage deliberate extensification or fallowing started in 1985 and later in 1990 regulations encouraging agricultural practices to conserve the environment and rural landscapes were enacted. Meanwhile, the Japanese Government officially announced its new agricultural policies in 1992 to promote the environment-conserving agriculture.

Under these programs in the developed countries a variety of agricultural practices, ranging from rigorous organic farming to alternative agriculture with low external input are being exercised. For the farmers practicing these environmentally sound farming a part of the reduction in their incomes due to reduced outputs may be compensated by the premium price paid by the health-conscious consumers. However, the majority of farmers in these countries are still adhering to the conventional agricultural practices with, at best, a little reduced use of chemical fertilizers and pesticides.

In most developing countries, agriculture has not yet undergone very drastic changes from its traditional form, but an increased pressure of population and cash economy begins to force farmers to intensify their farming practices, often accompanying the use of modern external inputs. Thus there is a worry that agriculture in all these developing countries might eventually follow the same track of diminishing sustainability as already trod by that in the developed countries in their course of agricultural intensification. People should realize that agriculture is in the pivotal point that governs the life and the environment and nothing is more precious than safe food and clean water that can be secured by sustainable agriculture.

The 3rd APEC Workshop on Sustainable Agricultural Development

Resource Speeches

The 3rd APEC Workshop on Sustainable Agricultural Development

Session 2

Plant Breeding and Water Management

The 3rd APEC Workshop on Sustainable Agricultural Development
16th to 22nd November 2003, Chinese Taipei

A Strategy to Maximize Maize Production while Reducing Nitrate Contamination to the Environment

Chia-Yin Tsai

Institute of Botany
National Taiwan University, *Chinese Taipei*

A Strategy to Maximize Maize Production while Reducing Nitrate Contamination to the Environment

Chia-Yin Tsai

Institute of Botany
National Taiwan University

Introduction

Plant nutrition, along with moisture, temperature, light intensity, and pest management interacts with the genetic composition of hybrids to determine maize grain production. However, nutrient stress especially from a deficiency of nitrogen (N) is the most frequent limitation for vegetative growth and grain yield. N-sufficiency during the growing season is important not only because N plays an important role in structural and metabolic functions, but also because it affects grain fill kinetics (Tsai et al., 1990). In order to meet N requirements for maximum kernel development, the plant must either take up most of its required N during the stage of vegetative growth, or maintain its ability to absorb inorganic N (maintained in an available form in the soil) throughout the entire growing season. However, maize hybrids vary substantially in their abilities to take up and utilize N nutrition during the growing season (Tsai et al., 1991). In addition, they also differ in yield potential.

Some of the areas covered in this presentation include: 1) effects of N sink on dry matter accumulation in maize kernels, 2) predictions of grain yield potential for maize hybrids based on the N sink capacity, 3) differences among maize hybrids in nitrogen uptake and utilization, and 4) genetic variations in the ability of maize inbreds to utilize ammonium (NH_4^+) nutrition. A better understanding of these areas should be helpful to come up with an efficient N management program and breeding strategy to increase grain yield while reducing nitrate ($N0_3^-$) contamination.

Effects of N sink on dry matter accumulation in maize kernels

Amino acids and sugars are two major nutrients required for the development of maize kernels. Movements of these two nutrients into kernels are interrelated (Lyznik and Tsai, 1989), and the movement of sugars was stimulated by amino acids (Tsai et al., 1990). Therefore, an ability to continuously deposit amino acids as proteins is an important mechanism to facilitate the movement of sugars into kernels. These nitrogenous compounds are stored temporarily in leaves and stalk during the period of vegetative growth (Tsai et. al., 1991). As the kernel develops, proteins in vegetative tissues are hydrolyzed and amino acids are transported into the kernel for its development. Tsai et al. (1978; 1980; 1983) proposed that zein and glutelin function as N sinks for the

deposition of these nitrogen compounds. They thereby prevent the accumulation of deleterious levels of free amides and ammonium. The accumulation of free amino acids in the kernel due to a small N sink capacity may generate a more negative osmotic potential that favors water movement but reduces solute, such as sugars, movement into the kernel. Thus, the yield response of grain to N fertilizer is enhanced by the presence of a large N sink in the kernel (Tsai et al., 1978; 1980; 1983).

Although all proteins in the kernel may function potentially as N sinks to the extent that their synthesis reduces the accumulation of free amino acids, zein and glutelin are considered to be the major N sinks. This is so because combined they contain more than 90% of the total N in the endosperm and 60% of the total N in maize plant at maturity (Tsai et al., 1980). Unlike glutelin, however, zein is the major storage protein, and its synthesis can be manipulated readily by N fertilization as well as by genetic means. Thus, increased N in the kernel due to N fertilization is confined primarily to zein, and nonzein protein i.e., albumin, globulin, and glutelin, increases only sightly (Tsai et al., 1978; 1980). This suggests that zein plays the primary functional role as a N sink in the kernel. The positive correlation between zein content, kernel weight, and grain yield reported by Tsai et al. (1978) indicates the potential of this system.

Using the much reduced zein content of the *o2* mutant compared to its isogenic normal counterpart as a model system, Tsai et al. (1980; 1983) showed the importance of zein in affecting the movement of photosynthetic assimilates into the kernel. Since *o2* is recessive and *o2* kernels can be readily distinguished from normal kernels on the same ear, utilization of a heterozygous plant for both *o2* and normal alleles should remove interplant variability and environmental interactions which could otherwise confound this type of study. $^{14}CO_2$ was supplied to heterozygous plants (B14*o2*xB37) at 26, 39, and 45 days post pollination to monitor the movement of radioactive sugars into kernels (Tsai et al., 1980). Under high N fertilizer conditions, these three stages represent early phase, leveling off, and termination of zein synthesis, respectively, for the homozygous *o2* in hybrid backgrounds. Normal kernels, on the other hand, had a higher rate of zein accumulation than *o2* during endosperm development and terminated zein synthesis at about 55 days post pollination. Under a high N condition (201 kg N/ha), the difference in radioactivity incorporated into *o2* and normal kernels was obvious as early as 26 days post pollination. At this early stage of development, *o2* kernels contained about 93% of the radioactivity found in normal kernels. The differences were more apparent as the synthesis of zein terminated in *o2*. The *o2* kernels contained 86% of radioactivity found in normal kernels at 39 days post pollination and only 54% at 45 days (Table 1). These results are consistent with the observation that the early termination of zein synthesis in the *o2* results in a decreased rate of dry matter accumulation in the kernel thereafter (Tsai et al., 1978). Under low N conditions, like *o2*, zein accumulation in normal endosperms was substantially reduced, and the amount of radioactive photosynthates incorporated into *o2* kernels was only slightly lower than incorporated into the normal kernels on the same ear, i.e., *o2* kernels

had about 95% of the radioactivity found in normal kernels at 39 days post pollination and 88% at 45 days.

The reduction of sugar movement into the kernel, as affected by the termination of zein accumulation or by a reduced N sink capacity, correlated well with a low osmotic potential observed in the mutant. At 39 days post pollination, *o2* kernels from a segregating ear had an osmotic potential of -8.2 bars as compared to only -4.4 bars for the segregating normal kernels (Table 1), a situation similar to that of the sucrose accumulation in the endosperm of *sh2* and other starch-deficient mutants where the accumulation of high sucrose content also generated a low osmotic potential to prevent the movement of free amino acids into the kernel (Lee and Tsai, 1985). Thus, the movement of carbon (C) and nitrogen into the kernel is interrelated and is under the influence of osmotic regulation. This more negative osmotic potential of the *o2* kernel than its normal counterpart also provides an explanation that all high-lysine mutants retain higher moisture content at maturity (Lambert et al., 1969). The dynamic response of zein synthesis to N fertilizer (which is essential to increasing productivity), coupled with the observation that the early termination of zein synthesis in the *o2* mutant under high N conditions results in a reduction of sugar movement into the kernel, suggest that zein is an effective N sink to regulate dry matter accumulation in the kernel, a major determinant for grain yield.

Predictions of grain yield potential for maize hybrids based on the N sink capacity

With the cost-price squeeze felt throughout the agricultural industry, the ability to predict maximum grain yield potential and N fertilizer requirements for maize hybrids should provide a critical management tool to increase production efficiency and thereby enhance energy utilization and total productivity. As indicated from the studies shown above, the kernel sink is a primary yield determinant for maize. Other studies also provide a similar conclusion that include: 1) the movement of sugars into the kernel is substantially reduced when the deposition of nitrogenous compounds in the kernel terminates (Tsai et al., 1980), 2) restoration of normal zein accumulation in a sink-defective type kernels allows the kernel to regain a normal dry matter accumulation (Tsai et al., 1983), 3) modification of the kernel sink in an early maturing hybrid with a short duration of grain filling (by receiving pollen from a full season hybrid) not only prolongs the grain filling period until much later in kernel development but also results in a much greater kernel weight (Tsai and Tsai 1990), 4) grain yield of a given hybrid is highly correlated with its ability to deposit nitrogenous compounds in the kernel N sink as induced by N fertilizer (Tsai et al., 1980; 1983; 1992), and 5) the movement of carbon and nitrogen into maize kernels is interrelated and subject to osmotic regulation (Tsai, 1983). Based on this information, I propose that the maximum yield potential of any

given hybrid can be predicted based on measurements of the C/N ratio and the N sink capacity in the kernel using two tangible parameters, i.e. 1) kernel weight, and 2) percent protein obtained at any level of N fertilizer .

Maize hybrids were grown at the Purdue Agronomy Farm on Chalmers silty clay loam soil. Replicated field plots (4 times) were spring-treated with 0, 67, 134, 201, 268, and 447 kg N/ha of anhydrous ammonia prior to planting. Residual N in the experimental plots was cropped out a year before the study. Under this condition, the zero N plot averaged about 15 kg N/ha of residual N plus mineralized soil N each year. Each main plot consisting of rows 76 cm apart and 23 long, was separated from the others by two buffer rows. Hybrids were randomly assigned to main plots and plant density was about 54,000 plants/ha. At maturity, ears were harvested by hand, shelled, moisture percentage of the grain determined, and yield calculated. Samples were drawn with a grain probe from the shelled corn and air-dried prior to analysis for 100-kernel weight and protein. Total N was determined by a micro-kjeldahl method and protein percentage was calculated by multiplying Kjeldahl N by a factor of 6.25. This study was conducted from 1979 to 1991.

As shown in Table 2, the grain yield of a given hybrid induced by N fertilization is highly correlated with percent protein ($r > 0.93$); even though protein content among hybrids may be negatively correlated. For pioneer 3732, percent protein and grain yield increased from zero added N to its maximum with 67kg N/ha. Protein and grain yield of B73xMo17, on the other hand, increased as the level of N fertilizer increased up to 201kg N/ha. The correlation of grain yields with percent protein agrees with previously reported zein data (Tsai et al., 1992). This supports a previous observation that percent protein in the grain may serve as a parameter for estimating amounts of fertilizer required for maximum yield (Russell and Pierre, 1980).

Although zein is considered the primary N sink, all proteins in the kernel are considered together as the kernel N sink. Since the synthesis of any protein will minimize free amino acid accumulation to prevent the lowering of osmotic potential and thereby facilitate sugar movement into the kernel (Tsai et al., 1980; 1983), the determination of total proteins, rather than zein is more practical and used as an estimation of the N sink parameter for this study.

Although movement of C and N into kernels could be influenced by source supplies (Tsai et al., 1990), the C/N ratio in the kernel of a hybrid grown under an usual condition is genetically determined (Zink, 1980). The C/N ratio can be determined by dividing kernel dry weight (mg/kernel) by percent protein. This produces a constant value, except under severe N stress conditions, indicative of the increased dry weight with each increase in percentage of protein. The higher C/N ratio obtained with zero added N was caused by severe N stress. Because the limited increases in dry weight induced by additional N are primarily in the form of starch, the C/N ratio should be calculated according to starch content rather than kernel dry weight. Since the starch content for all the hybrids tested varied only from 65% to 75% of the total kernel dry weight, an average of 70% was considered an acceptable value in these studied. The C/N ratio thus

calculated appears to be hybrid-specific (Table 3) and remain nearly constant during the years tested. It thus permits the prediction of kernel weight for any given percentage of protein produced. The C/N ratio of the B73xMo17 hybrid is 26 when grown with 137 kg N/ha or more of N fertilizer (Table 3). This ratio predicts that for every percentage increase in kernel protein, the kernel should accumulate 26 mg of starch simultaneously. Therefore, with this C/N value, kernel weight and grain yield could be predicted for any hybrid at any percentage of protein produced in the kernel. N stress condition should be avoided since a higher than normal C/N ratio is induced and kernel primordia in the ear are aborted.

Most hybrids have a maximum percentage of protein attainable around 12% (Russell and Pierre 1980); although a higher value is possible, 12% represents a realistically achievable value for any given hybrid. Using the reference values obtained with B73xMo17 at 134 kg N/ha (Table 4), where the kernel weight, percent of protein and grain yield are 330mg, 9.0%, and 110q/ha, respectively, the predicted kernel weight at 12% percent protein can be calculated as follows: Since 12% protein represents an increase of 3.0% over the tested reference value of 9.0%, the predicted kernel weight is 330 mg + (26 mg x 3.0) = 408 mg. The N sink capacity can be calculated by multiplying kernel weight with percent protein. The N sink capacity at 9% and 12% protein are is 29.7 mg/kernel (330 mg x 9.0%) and 49.0 mg/kernel (408 mg x 12%), respectively. The conversion factor is determined by dividing the N sink capacity at 12% by that at 9.0% i.e. 49.0/29.7 which gives a factor of 1.65. The predicted maximum yield (at 12% protein) of this hybrid is, therefore, equivalent to 182 q/ha or 110 q/ha x 1.65. Grain yield predicted for any level of protein from the reference values obtained with various levels of N fertilizer, except zero N, agree very well with yields actually observed for B73xMo17 (Table 4). Evaluation of all 16 hybrids under various levels of N fertilizer further support this conclusion. The equation for predicting grain yield at any percentage of protein for a given hybrid is:

$$Y_2 = Y_1 [(RP_2 - RP_1 + W_1) P_2/W_1P_1].$$

Where Y_2: Predicted yield at a given percent protein.

Y_1: Reference yield value observed at a given N level

W_1: Reference kernel weight observed at a given N level

P_1: Reference protein percent observed at a given N level

P_2: Expected protein percent

R: C/N ratio of the given hybrid

The C/N ratio is not only important for predicting kernel weight and grain yield, but may also be used as a selection index for high yielding varieties. Because the C/N ratio predicts the amount of starch that can be produced with each percentage protein increased, the selection of hybrids with higher C/N ratio should yield better than hybrids with lower C/N ratios. High-yielding hybrids have a high C/N ratio and a small amount of zein (or low percentage of total

protein); therefore, the N sink (zein protein) will continue to increase in response to N fertilization and result in a greater kernel weight until N sink saturation is achieved (or when total protein in the kernel approaches 12%). Low-yielding hybrids, on the other hand, have a low C/N ratio and large quantities of zein (or a high percentage of total protein). They not only have less C movement into the kernel for every unit of N but also reach N sink saturation rapidly with only a small amount of N fertilizer. This explains why, in general, grain yields in maize are usually negatively correlated with protein content (Dudley et al., 1977), although for a given hybrid, the grain yield induced by N fertility is highly correlated with its zein or protein content (Tsai et al., 1983; 1984). A simple extrapolation of this information indicates that the percent grain protein may serve as a parameter for estimating amounts of N fertilizer required for maximum yield of a given hybrid. Studies with these 16 hybrids support this hypothesis.

Differences among maize hybrids in nitrogen uptake and utilization

Maize hybrids not only vary in yield potential, their abilities to utilize N fertilizer are also different. We have grouped maize hybrids grown in the U.S. Corn Belt into three categories based on grain yield response to N fertilizer treatments (Tsai et al., 1984). These three categories are: 1) low N-responsive types, represented by Pioneer 3732, which perform well under N stress conditions and reach their maximum yield potential with relatively low levels of applied N; 2) Intermediate types, such as B14xOh43, which respond to moderate N rates; and 3) N-responsive types, such as B73xMo17, which respond dynamically to additional N. However, the actual level of soil N conditioning a yield response within each group may be affected by plant populations and environmental factors such as moisture and temperature.

One of the major factors that distinguishes the N-responsive type from the low N-responsive type is its ability to take up large quantities of N during the period of grain-fill (Tsai et al., 1984). When grown under 201 kg N/ha at 54,000 plants/ha, Pioneer 3732, a low N-responsive type, took up and stored about 90% of its final N content by the 10th week after planting. This hybrid tolerates low levels of N in soil during the grain-fill period which makes grain production more predictable on coarse textured soil and at high plant populations. In contrast, the higher yielding hybrid B73xMo17 at the same plant density absorbed and stored only about 65% of its final N by the 10th week after planting. Thus, B73xMo17 type hybrids benefit more than Pioneer 3732 from higher levels of N fertilizer and from inhibiting nitrification or split applications of N because of their ability to take up large quantities of N after mid-silk.

When ammonical N was applied prior to planting without inhibiting nitrification, generally results in only limited amounts of N being available for plant uptake 10 weeks after planting due to denitrification, leaching, or

volatilization losses of N (Huber et al., 1977; Nelson and Huber, 1980). When available N from soil or readily available vegetative sources are not sufficient to meet the requirements of developing kernels, the plant may cannibalize enzymatic and structural proteins as sources of N. Thus, to compensate for shortage of N during grain-fill, N-responsive hybrids could conceivably cannibalize more N components from leaf and stalk tissues than low N-responsive types with the ultimate result being less than maximal yield performance and the predisposition of weakened stalks to stalk rot.

To test the hypothesis that the kernel-sink induced nutrient deficiency of N-responsive hybrids may result in cannibalization of N components, maize hybrids Pioneer 3732, B37xW64A, and B73xMo17 (representing different maturation dates and a range in yield potential) were grown at the Purdue University Agronomy Farm in 1984 on field plots which had been spring treated prior to planting with either 134 kg N/ha or 402 kg N/ha plus 0.5 kg nitrapyrin. These two N treatments were chosen for the studies to accentuate the N effect. The experimental design was a randomized complete block with three replicates. Ear-leaf and kernel samples were collected at mid-silk, 15, 30, 45, 50, 55 and 60 days post-pollination. Collections at 5-day intervals for stages beyond 45 days post-pollination were necessary to determine the time of RuBP carboxylase cannibalization and its effect on the kinetics of kernel dry matter accumulation. Whole plant tissue was collected at the mid-silk stage and at maturity for N analysis. At each sampling, ear leaves were frozen in liquid N immediately after collection, stored at -80°C before measurement of RuBP carboxylase activity (Evans and Seemann, 1984), and analyzed for cannibalization of proteins on slab gels by an SDS-polyacrylamide gel electrophoresis system similar to that of Laemmli (1970). Whole plant tissues, including leaves and stalk, were air-dried at 40°C, ground to a powder and analyzed for total N. N content was multiplied by a factor of 6.25 to convert it to percent protein. Kernels were oven-dried at 103°C prior to determining dry weight.

The literature is replete with evidence for the redistribution of N from vegetative tissues to the kernel sink during the period of grain-fill. Variation in N translocation from vegetative tissues to grain are genetically controlled (Below et al., 1981; Swank et al., 1982; Anderson et al., 1985). Protein concentrations in leaf tissues of the three hybrids tested, Pioneer 3732, B37xW64A, and B73xMo17 decreased from the mid-silk stage to maturity (Table 5). B73xMo17, a N-responsive or high-yielding hybrid, had the least amount of protein remaining in the leaf tissue at maturity since vegetative proteins were extensively cannibalized. Pioneer 3732 and B37xW64A are low N-responsive and intermediate types, respectively, and had more proteins remaining in the tissues than B73xMo17. Because nitrapyrin is an effective nitrification inhibitor in the Corn Bely (Huber et al., 1977; Nelson and Huber, 1980), application of 402 kg N/ha with nitrapyrin should provide available N for uptake during the grain-fill period and minimize cannibalization of enzymatic and structural N components in the tissues. The greater amount of protein retained in tissues at maturity with the treatment confirms this hypothesis.

RuBP carboxylase, a key enzyme responsible for CO_2 fixation, is the most abundant protein in leaves and a potential source of N for kernel development. The degree of RuBP carboxylase cannibalization generally varies inversely to the availability of N. The RuBP carboxylase activity of B73xMo17 decreased rapidly (Table 6) as the enzyme was hydrolyzed about 45 days post-pollination in insufficiently N fertilized plants (Tsai et al., 1991). This destruction of RuBP carboxylase from leaf tissues of N-responsive hybrids due to N stress during grain-fill resulted in early termination of dry matter accumulation and prevented a further increase in kernel weight and grain yield (Table 7). The highest level of available N (402 kg N/ha) stabilized with nitrapyrin evaluated in this study delayed the hydrolysis of RuBP carboxylase and other proteins, and enzyme activity was maintained up to 55 days post-pollination (Tsai et al., 1991). Accordingly, the duration of kernel dry matter accumulation was prolonged beyond that observed with the lower N treatment. These results are consistent with an observation that continuous N input into the plant and maintenance of N in the leaf tissue are important for continuing photosynthetic activity (Christensen et al., 1981; Swank et al., 1982).

The low N-responsive hybrid, on the other hand, maintained RuBP carboxylase activity throughout the 45 days post-pollination period (Table 6) at which time dry matter accumulation in the kernel was complete (Table 7). Although this enzyme can be preserved in low N-responsive hybrids with higher levels of N, no beneficial result is obtained because the requirement of N in the kernel for dry matter accumulation terminates at 45 days post-pollination. These studies clearly demonstrate that there are wide variations in hybrid response to N fertilization; and maintenance of N sufficiency throughout the crop season is critical to preserve RuBP carboxylase activity, strengthen stalk quality, and maximize grain production for N-responsive type hybrids such as B73xMo17.

Genetic variations in ability of maize inbreds to utilize ammonium nutrition

The fact that certain hybrids require N uptake throughout the growing season clearly suggests an important role of NH_4^+ nutrition for maize grain production. Although NH_4^+-N is the most prevalent form of N fertilizer applied for maize, it may be rapidly converted to NO_3^- in the soil because of nitrification. NO_3^- is susceptible to leaching and denitrification losses; therefore, the pre-plant applied N may not be available for plant utilization during the period of grain-fill. N deficiency during grain-fill may result in the early termination of dry matter accumulation due to an extensive proteolysis of leaf proteins including RuBP carboxylase (Tsai et al., 1991). Stephenson et al. (1969) reported that 50% of the added N was evolved. Thus, if NO_3^--N is not assimilated by plants or immobilized by microorganisms, it may be lost through leaching and denitrification (Prasad et al., 1971). In contrast to NO_3^-, NH_4^+ is held in soil by the cation exchange complex from which it is released slowly

into the soil solution for uptake by plants. The availability of nitrification inhibitors to reduce these losses provides an additional approach to increase the efficient utilization of nitrogen in crop production. As the concern over $N0_3^-$ pollution increases, NH_4^+ nutrition will undoubtedly become more important for crop production especially when high efficient nitrification inhibitors are being developed as N management tools.

In spite of the high efficiency of NH_4^+ nutrition for crop production, maize hybrids may not perform well under NH_4^+-N exclusively. This is because breeding programs and selection have been conducted under predominantly $N0_3^-$-N environments that could result in eliminating the trait of high efficiency in NH_4^+ assimilation. Therefore, as a first step towards developing maize hybrids capable of performing under NH_4^+-N, germplasms were evaluated for the efficiency of NH_4^+ assimilation which includes activities of NH_4^+ assimilating enzymes, photosynthetic enzymes such as PEP carboxylase, and the ability of NH_4^+ uptake.

The efficiency of NH_4^+ assimilation via the glutamine synthetase (GS)/glutamate synthase (GOGAT) and glutamate dehydrogenase (GDH) systems may be key regulatory steps enhancing N utilization and CO_2 assimilation in maize. When maize plants are grown in the presence of a nitrification inhibitor, the level of NH_4^+ may increase substantially - especially during early stages of growth. Unlike $N0_3^-$, NH_4^+ is relatively toxic at low concentrations *in vivo* (Anderson and Done, 1977) and must be assimilated immediately in the root by the reductive amination of an available carboxylic acid to form a non-toxic amino acid prior to translocation (Ivanko and Ingversen, 1971). The NH_4^+ directly absorbed or available through reduction of $N0_3^-$ is assimilated into organic N either by 1) the reductive amination of α-ketoglutaric acid by GDH to form glutamic acid or 2) by conjugation with glutamic acid to form glutamine by GS. The amide amino group of glutamine is then transferred to α-ketoglutaric acid to form glutamic acid by GOGAT (Miflin and Lea, 1977). The GS/GOGAT system is considered as the major pathway for NH_4^+ assimilation. However, based on a determination of NH_4^+ assimilation in *in vitro* and the calculation of organic N accumulated in the shoot after seedling growth on NH_4^+, our studies indicate that GS/GOGAT system alone was not sufficient to account for all of the organic N transported to the shoot (Handa et al., 1985). Thus, one cannot rule out the possibility that GDH may play an important role in NH_4^+ assimilation in the root, especially when plants are grown under high concentrations of NH_4^+.

A previous study has shown that 10 mM NH_4^+ provides a near optimum N condition for seedling development (Xu et al., 1992). Therefore, maize inbreds were grown at 10 mM and a high concentration of 50 mM NH_4^+-N to evaluate for their sensitivities of seedling growth to NH_4^+ nutrition. Of the 41 inbred lines screened, only two inbreds grew vigorously with 50 mM NH_4^+-N (more than 70% dry weight of the 10 mM control). Thirty-two inbreds grew very poorly with 50 mM NH_4^+ as the only source of N (less than 33% of the 10 mM control)

(Wu et al., 1998).

Va26, A661, H95, Hi31, Pi6875-370, ICAL210, PH9, CI66, A632, TA85-17, and Pi 77-4239, which represent different degrees of sensitivity to NH_4^+-N, were selected for further growth analysis under mixtures of NH_4^+-N and $N0_3^-$-N. With the exception of A632, all other 10 inbreds studied preferred a high proportion of N in the $N0_3^-$ form (66% or 100% $N0_3^-$-N)(Table 8). These observations are expected because of breeding programs and selection under predominantly $N0_3^-$ environments which might have inadvertently eliminated the trait for efficient NH_4^+ utilization. The finding that certain inbreds such as A632 could tolerate high proportion of N in NH_4^+ form for growth is important for developing maize hybrids which can capitalize on the efficiency of NH_4^+-N for high yield production and thereby permit the greater use of management practices, such as inhibiting nitrification, to minimize potential $N0_3^-$ pollution.

Because NH_4^+ assimilation involved three components: organic carbon skeletons (derived from PEP and RuBP carboxylase activities), assimilating enzymes (GDH, GS, and GOGAT), and NH_4^+ uptkake, efforts were made to determine which components are responsible for the ability or inability of maize inbreds to utilize NH_4^+ nutrition. As shown in Table 9, the correlation coefficient between dry weight accumulation and the activity of GS (r^2= 0.09), GOGAT (r^2= 0.004), GDH (r^2=0.016), or PEP carboxylase (r^2= 0.24) among the 11 inbreds studied was very low. Likewise, there was no correlation between dry weight and NH_4^+ uptake (r^2= 0.05, Table 10). From these data, it is clear that no one component is entirely responsible for enhanced seedling growth with high NH_4^+ levels and that a more complex interaction between enzymes exists. In other words, certain inbred lines retain the ability to effectively utilize ammonium, but adapt various combinations of mechanisms to cope with NH_4^+ pressure and thereby allow seedling growth and development in the presence of NH_4^+ in high concentrations. Therefore, plant breeders should be able to exploit this variability and create hybrids with enhanced performance under predominantly NH_4^+-N conditions. A preliminary study with maize hybrid Tainan 17 and its inbred parents supports this hypothesis. In addition, a field experiment indicated that crosses that involved the Mo17 family responded positively to inhibiting nitrification (Tsai and Huber, 1996) which provided a larger portion of the N in the ammonium form. These studies support the notion that grain yield of maize could be greatly increased through N management and selection for hybrids that are efficient for NH_4^+-N utilization.

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Table 1. Osmotic potential and movement of radioactive sugars into 39-day-old endosperms of normal and *o2* kernels obtained from B14*o2*xB37 plant grown with 201 kgN/ha.

Genotype	Osmotic potential	Sugars incorporated
	x 10^5 Pa	cpm
Normal	- 4.4[a]	36,450
o2	- 8.2[b]	31,340

Data adapted from Tsai et al. (1980; 1983).
Means followed by the same letter in each column are not significantly different at 5% level of probability.

Table 2. Kernel dry weight, percent protein and grain yield of maize hybrids Pioneer 3732 and B73xMo17 supplied with different levels of N fertilizer[1].

	Pioneer 3732			B73xMo17		
N level	Dry weight	Protein	Yield	Dry weight	Protein	Yield
KgN/ha	mg/kernel	%	q/ha	mg/kernel	%	q/ha
0	302[a]	8.8[a]	43.4[a]	293[a]	7.3[a]	27.3[a]
67	370[b]	11.1[b]	83.7[b]	312[a]	8.2[b]	94.2[b]
134	368[b]	10.9[b]	88.0[b]	330[b]	9.0[c]	109.7[c]
201	370[b]	11.5[b]	92.4[b]	347[bc]	9.5[cd]	123.4[d]
268	369[b]	11.5[b]	90.5[b]	349[bc]	9.4[cd]	129.0[d]
447	372[b]	11.4[b]	93.6[b]	351[c]	9.8[d]	130.8[d]

Data from 1980.
Means followed by the same letter in each column are not significantly different at 5% level of probability.

Table 3. Grain yields and C/N ratios of various maize hybrids evaluated at 67, 134, 201, and 447 kgN/ha.

Hybrid	Grain yield 67	134	201	447	C/N
	----------	q/ha	----------		Ratio
B73xMo17	102	115	123	127	26
Mo17xB73	116	120	123	127	26
H99xB14	96	113	117	119	23
B14xH99	89	117	114	123	23
Pioneer 3732	82	84	89	87	23
Va26xB14	77	95	106	110	22
B14xVa26	87	96	107	107	22
B14xB37	69	80	97	106	22
Pioneer 3780	92	97	96	99	21
B14xOh43	86	92	90	102	21
Oh43xB14	78	95	96	102	21
A545xB14	62	95	102	103	19
B14xA545	78	96	96	99	19
W64AxB37	66	81	86	85	19
B37xW64A	66	76	80	85	19

Data from 1979 and 1980. BLSD = 11 q/ha.

Table 4a. Observed values for kernel weight, % protein and grain yield of B73xMo17.

N level	Kernel wt.	Protein		Starch	C/N	Grain yield
Kg/ha	mg/kernel	%	mg/kernel	mg/kernel	ratio	q/ha
0	293[a]	7.3[a]	21.4	205	28	27[a]
67	312[a]	8.2[b]	25.6	218	27	94[b]
134	330[b]	9.0[c]	29.7	231	26	110[c]
201	347[bc]	9.5[cd]	33.0	243	26	123[d]
268	349[bc]	9.4[cd]	32.8	244	26	129[d]
447	351[c]	9.8[d]	34.4	246	25	131[d]

Data from 1980.
Means followed by the same letter in each column are not significantly different at 5% level of probability.

Table 4b. Predicted and observed grain yields of B73xMo17 at various percentage of protein obtained under different levels of N fertilizer.

	Predicted yield using following % of protein						Observed
N level	7.3	8.2	9.0	9.5	9.4	9.8	Yield
Kg/ha	----- predicted grain yield (q/ha) ----						q/ha
67	33	---	94	96	103	97	94
134	38	110	---	112	120	113	110
201	42	121	121	---	132	124	123
268	41	118	118	121	---	122	129
447	44	127	127	130	138	---	131
Maximum	63	181	182	184	197	186	

Table 5. Protein concentration in the leaf tissue of maize hybrids fertilized with two levels of N fetilizer.

Hybrid	Stage	134 kgN/ha	402 kgN/ha*
		--------- % protein ---------	
Pioneer 3732	Mid-silk	15.8 ± 1.7	19.3 ± 3.4
	Maturity	6.4 ± 0.9	8.8 ± 0.7
B37xW64A	Mid-silk	16.0 ± 0.4	19.4 ± 2.0
	Maturity	6.6 ± 0.9	9.5 ± 0.5
B73xMo17	Mid-silk	13.8 ± 1.2	17.0 ± 1.8
	Maturity	5.9 ± 0.9	7.1 ± 0.6

*Stabilized with 0.55 kg nitrapyrin/ha
Data adapted from Tsai et al. (1991).

Table 6. RuBP carboxylase activity in maturing ear leaves of Pioneer 3732 and B73xMo17 fertilized with two levels of N fertilizer.

			Days after pollination					
Hybrid	N level	Midsilk	15	30	45	50	55	60
	Kg/ha	---------- nCi incorporated/g. fresh weight ----------						
Pioneer 3732	134	256	256	312	304	60	0	0
	402*	595	812	926	450	472	438	0
B73xMo17	134	498	394	600	212	24	18	0
	402*	376	550	513	335	326	286	0

*Stabilized with 0.55 kg nitrapyrin/ha
Data adapted from Tsai et al. (1991).

Table 7. Kernel dry weight during development and grain yield of Pioneer 3732 and B73xMo17 fertilized with two levels of N fertilizer.

Hybrid	N level	Days after pollination						Grain yield
		15	30	45	50	55	60	
	Kg/ha	----------		mg/kernel		----------		q/ha
Pioneer 3732	134	30	174	297	276	280	304	99
	402*	31	167	290	298	305	306	101
B73xMo17	134	35	172	289	303	315	321	105
	402*	40	186	304	331	369	370	124

*Stabilized with 0.55 kg nitrapyrin/ha
Data adapted from Tsai et al. (1991).

Table 8. The effect of N forms (30 mM) on total seedling dry matter accumulation in 11 maize inbreds.

Inbreds	NH_4^+ (mM)/NO_3^- (mM)			
	30/0	20/10	10/20	0/30
	----------	Dry weight/seedling		----------
Va26	0.76	1.07	1.23	1.21
Pi6875-370	1.46	1.75	2.15	1.70
C166	0.99	1.42	1.79	1.75
H95	1.39	1.66	2.22	1.94
A661	1.28	2.23	2.06	1.94
PH9	0.73	0.86	1.06	1.09
A632	0.92	0.98	1.29	1.20
Hi31	0.62	1.17	1.14	1.49
Pi77-4239	0.60	1.07	1.15	1.63
TA85-17	0.39	0.65	0.83	0.81
ICAL210	0.63	0.95	1.20	1.21

Data adapted from Wu et al. (1998).

Table 9. Relationship between seedling dry weight and enzyme activity of NH_4^+ assimilation and PEP carboxylase in 11 maize inbreds.

Genotype	Dry weight	GS	GOGAT	GDH	PEPcase
	g/seedling	---------- unit/mg protein/min ----------			
Va26	0.84	0.67	0.018	0.015	0.29
Pi6875-370	0.66	0.93	0.038	0.021	0. 19
C166	0.64	0.83	0.073	0.032	0.55
H95	0.52	1.30	0.071	0.021	0.39
A661	0.51	0.83	0.018	0.036	0.35
PH9	0.51	0.52	0.021	0.019	0.65
A632	0.43	0.97	0.049	0.034	0.22
Hi31	0.37	0.33	0.051	0.026	0.64
Pi77-4239	0.34	0.24	0.040	0.023	---
TA85-17	0.30	0.67	0.009	0.028	0.51
ICAL210	0.30	0.44	0.050	0.031	0.49

Data adapted from Wu et al. (1998).

Table 10. Relationship between NH uptake activity and seedling dry weight of 11 maize inbreds.

Genotype	Dry weight	Uptake
	g/seedling	u mol/g FW/h
Va26	0.84	2.25
Pi6875-370	0.66	2.30
C166	0.64	1.43
H95	0.52	1.45
A661	0.51	4.25
PH9	0.51	2.67
A632	0.43	1.26
Hi31	0.37	2.90
Pi77-4239	0.34	1.64
TA85-17	0.30	1.56
ICAL210	0.30	0.31

Data adapted from Wu et al. (1998).

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Rotational Cropping and Irrigation Prevailed in Chinese Taipei

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Abstract

Uneven distribution of precipitation in space and time, together with lack of suitable storage dam sites due to weakness in geological land formation have caused the water utilization in Taiwan under unfavorable condition, regardless of its annual average precipitation being one of the highest in the World. Scarcity in water resources utilization still occurred so often that the rotational cropping pattern and rotational irrigation had to be developed to cope with that, the limited water resources could be shared equally by rotation with more water users; and the efficiency of water utilization could be enhanced by precisely arranging water distribution schedule also by rotation. In particular, during the period of 1950s to1980s, these two practices had assisted the agriculture of Taiwan in fulfilling its designated contemporary goal of producing adequate food to meet the need of that era with comparatively small amount of water. This achievement might attribute to the technical renovation on water management and heavy investment in the improvement of irrigation facilities. Contemplatively, these practices had enabled water controllers to convince water users that, the scarcity of water is being distributed equitably to a maximum extent so that the use of water in the field could maintain orderly, of which might ascribe equally or even more than the technical amelioration and heavy investment to the success and sustainability of water management. Moreover, cropping rotated with paddy rice, upland crops and sugarcane has extended the paddy wet land covering area, which is deemed to be in favor of conserving ecosystem and enhancing biodiversity for the environment. Recognizing the fact that the profit of irrigation is no longer able to pay the strict rotational cropping and irrigation, these two practices have gradually relaxed and modified nowadays. The Government agency concerned is aware of this change and tries to preserve and apply the spirit of equity of these two practices to the allocation of agricultural resources in a more sustainable way.

Key words

1. Rotational cropping pattern. 2. Rotational irrigation. 3. Equity.
4. Water scarcity 5. On-farm and off-farm irrigations

I. Introduction

1. 1 Natural Water Environment

Taiwan is an island oblong in shape, 142 km in width and 383 km in length, and located in the West Pacific Ocean, east of the Chinese mainland with an area of 35,961 km^2. The climate is subtropical and characterized by high temperature, heavy precipitation, and violent winds. Annual precipitation over the island averages 2,504 mm. The annual availability of water resources from precipitation varies from 60 billion m^3 to 120 billion m^3, of which about 20 to 25 per cent of them were utilized in the last 10 years.

In terms of depth, the annual average precipitation of Taiwan is the third highest in the World; but per capita precipitation used is at 4,030 m3/person/year; contrarily this amount is the third lowest compared to the lowest and 2nd lowest of Egypt and India at 951 and 3,795 m3/person/year respectively. The precipitation utilization rates in the last ten years varied from 22% to 14%. Of the utilized water resources, only 24 to 28 per cent of them were taken from the existing 41 small reservoirs. The shares of water utilization to agriculture, domestic water supply, and industry, in the Year of 2000 for example, are about 71.5%, 17.7% and 11.8% respectively. In the same year, paddy rice irrigation, fishery and animal industrial sub-sectors shares 83, 16 and 1 per cent of the total of agriculture respectively. The detailed water resources related physical features are shown in Fig 1.

1.2. Agriculture and Irrigation

1. Agriculture

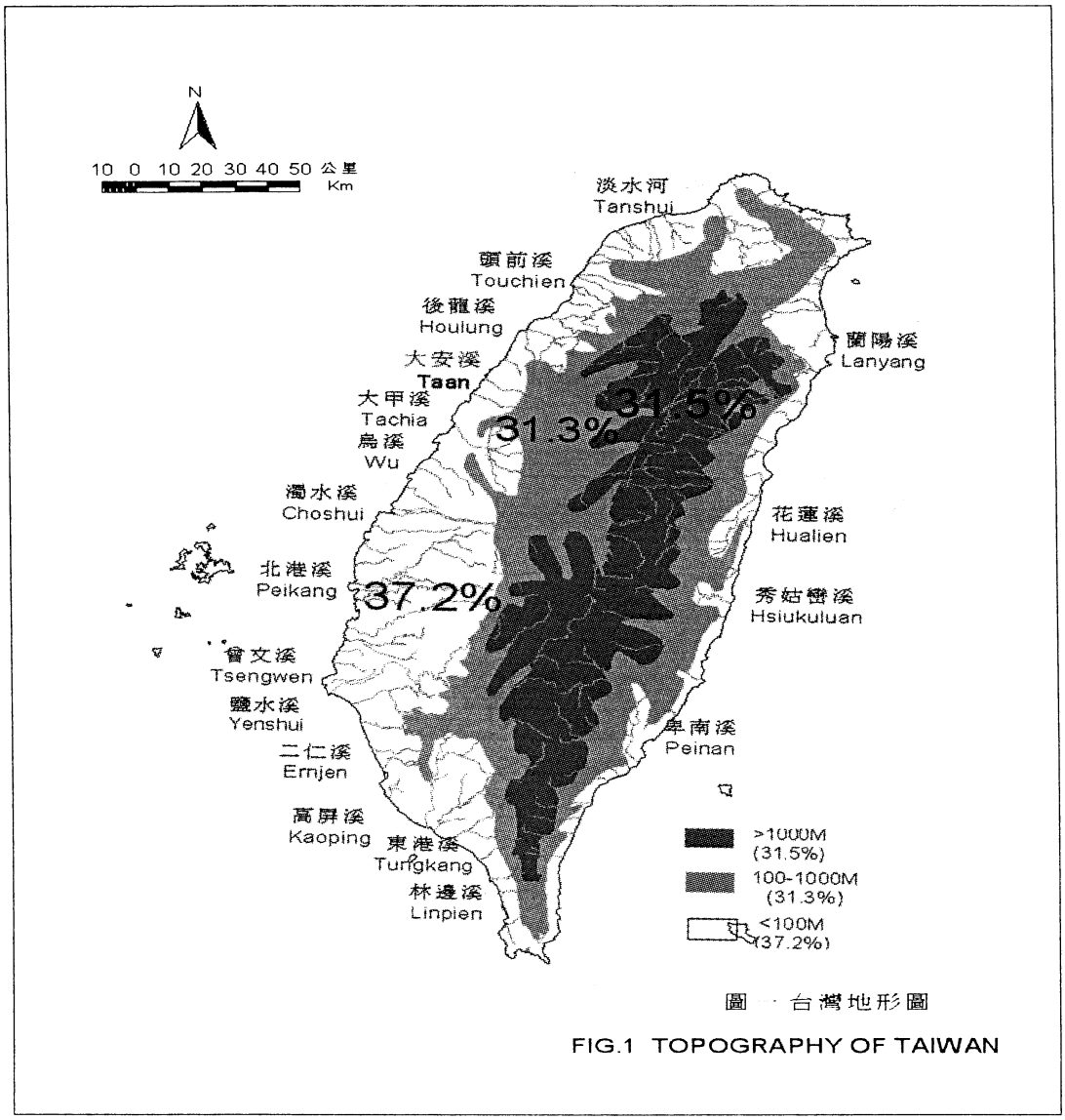
The existing arable of Taiwan is approximately 855,073 ha, including 444,456 ha for paddy and 410,616 ha, upland crops. The detailed components of different land utilization are shown in Figure 2. Agricultural production policy is to maintain the balance between productions and marketing, livelihood and ecology, and improve the production quality.

2. Irrigation

The history of developing large irrigation schemes in Taiwan could be traced back up to the Dutch colonial period from 1609 to 1661, Ming-Chung/ Dynasty from 1662 to 1683; Ching Dynasty from1684 to 1895; Japan's colonization from 1895 to 1945, and restoring to the Republic of China (Taiwan) after World War II from 1945 up to present. During these periods, the irrigated area in Taiwan had increased from 8,400 ha in 1600s to the highest of 560,000 ha in 1940s, and has decreased to 360,000 ha now. The period of Ming-Chung/Chin Dynasty was the only period that irrigation systems were developed and operated by the users, i.e. a real participatory irrigation management (PIM) under the quasi subsistence agriculture. After adopting mass rice production as the policy for foreign exchange earnings, and food self-sufficiency or food security in 1908s, the Government has involved more deeply in the development and management of irrigation systems (Ko 1997).

About 85 per cent of existing irrigated area in Taiwan is managed and

operated by 17 Irrigation Associations (IAs). The Irrigation Associations are the autonomous farmers' cooperative bodies, which previously were characterized by high water uses' participations, including payment for operation and maintenance and for substantial portion of system improvement. Presently, users' participation in terms of financial self-sufficiency has declined totally, and water users are no longer required to pay any water fee, while the Government has become obligated to provide reasonable funds every year to IAs for keeping the system operable since 1995. Any study on agricultural irrigation should refer to IAs.



Sources: Water Conservancy Bureau, Ministry of Economic Affairs

Fig. 1 Distribution of Taiwan

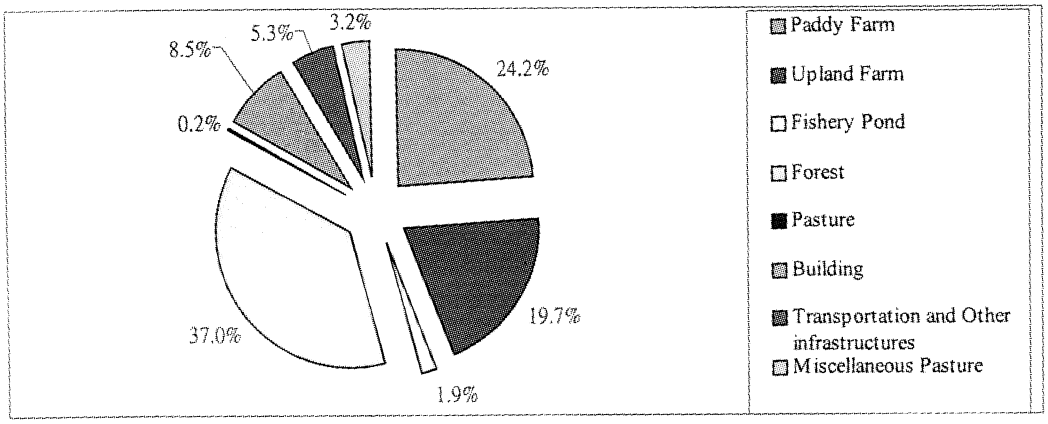


Fig. 2 Distribution of Land Utilization in Taiwan Area, 1999

II. Traditional Method to Cope with Water Scarcity

2.1 Rotational Cropping

Given the above-mentioned unfavorable precipitation distribution, water shortage for irrigation almost reoccurs once every five to seven years during the dry season of winter; however, the temperature and soil conditions in Taiwan are in favor of growing two crops of paddy rice wherever and whenever water resources are available, As rice is the staple food of the local inhabitants, traditionally, farmers would grow paddy rice as possible as they could when Taiwan was still in the subsistence agriculture. Non-rice crops might be grown after harvesting irrigated paddy at the beginning of dry season. Those non-rice crops, which consumed much less water than paddy, would absorb the residual moisture in the soil after irrigation for germination; then they would grow in the semi rain-fed condition. Once or twice of irrigations depending upon water availability would be given to upland crops. When water resources are sufficiently for growing paddy rice, farmers would grow rice; otherwise the upland crops would be their second choice. This rotational and diversified cropping pattern has prevailed for hundreds years in Taiwan.

There were some cases, when upland crops could not receive sufficient water from irrigation or rainfalls, they would produce lower yield or even suffer from damages. Farmers practicing this kind of rotational or diversified cropping were usually aware of the existence of risk; however, through their long-term trial-and-errors process, they eventually would gain sufficient experiences to undertake the most profitable diversified cropping in the long term.

2.2 Rotation Irrigation

The practice of rotational irrigation in Taiwan had been formulated about two hundred years ago in the area where water shortage was inevitable. The time of irrigation was based upon the area farmers owned and determined by burning a length of joss-stick to count the time of irrigation.

After the restoration of Taiwan from Japan's colonization in 1945,

systematic research on water application methods for paddy rice was conducted in the Chianan Irrigation Association by Prof. C. king of National Taiwan University. Information from these experiments coupled with actual demonstration experiences in the new canal system gave confidence to the irrigation engineers to develop the specifics of "Rotational Irrigation." It had rapidly displaced the conventional continuous irrigation.

III. Modernized Rotational Cropping Pattern

3.1 Three-year Rotational Cropping Pattern

One of the most sophisticated rotational cropping patterns designed in Asia is located in the Chia-nan Irrigation system situated in the south of Taiwan. It began its operation in 1927 covering a total irrigated area of 150,000 hectares when the system completed its construction. The area comprises about 8 per cent of clay soil and the remaining is sandy loam to clay loam. Annual rainfalls over the area are about 2,500 millimeters (mm). This amount of rainfall should have been sufficient to grow two crops of paddy annually. Unfortunately, the about 91 per cent of annual run-off concentrates in the raining season from May to September each year, and the geological condition is neither in favor to built water storage facilities. As a result, the developed water resources were only sufficient to grow one crop of paddy rice in the monsoon season in the one-third of the total newly developed area. Consequently, a "three-year rotational cropping pattern" was developed and practiced, i.e. Rice (monsoon)-upland crops-sugarcane-green manure, each piece of land within three years. The more details are illustrated in Fig 3 below.

3.2 Corresponding System Design

For enabling the irrigation schemes to carry out "Three-Year-Rotational Cropping Pattern", the entire newly developed irrigation areas were divided into 150-hectare unit each, namely rotational cropping unit; each unit is further subdivided into three sub-rotational units with 50 hectares each. Three major crops, namely paddy rice, upland crops, and sugarcane were grown in each sub-unit by turn within three years as a rotational cycle. The layout of irrigation and drainage canal either on-farm or off-farm system was so designed to fit the practice of the rotational cropping. In this connection, each rotational unit with three sub-units has its own individual off-take gates. In particular for the design of irrigation system, among all rotation units or sub-units, canals in different units would never be connected or mixed among each other.

3.3 The Practice of Rotation Cropping

As above-mentioned, for instance, when one of the three sub-units would receive water sufficient for producing one crop of paddy rice in the summer; the second sub-unit would be given irrigation water only in the dry seasons of winter and spring for the need of growing; while the third sub-unit, growing

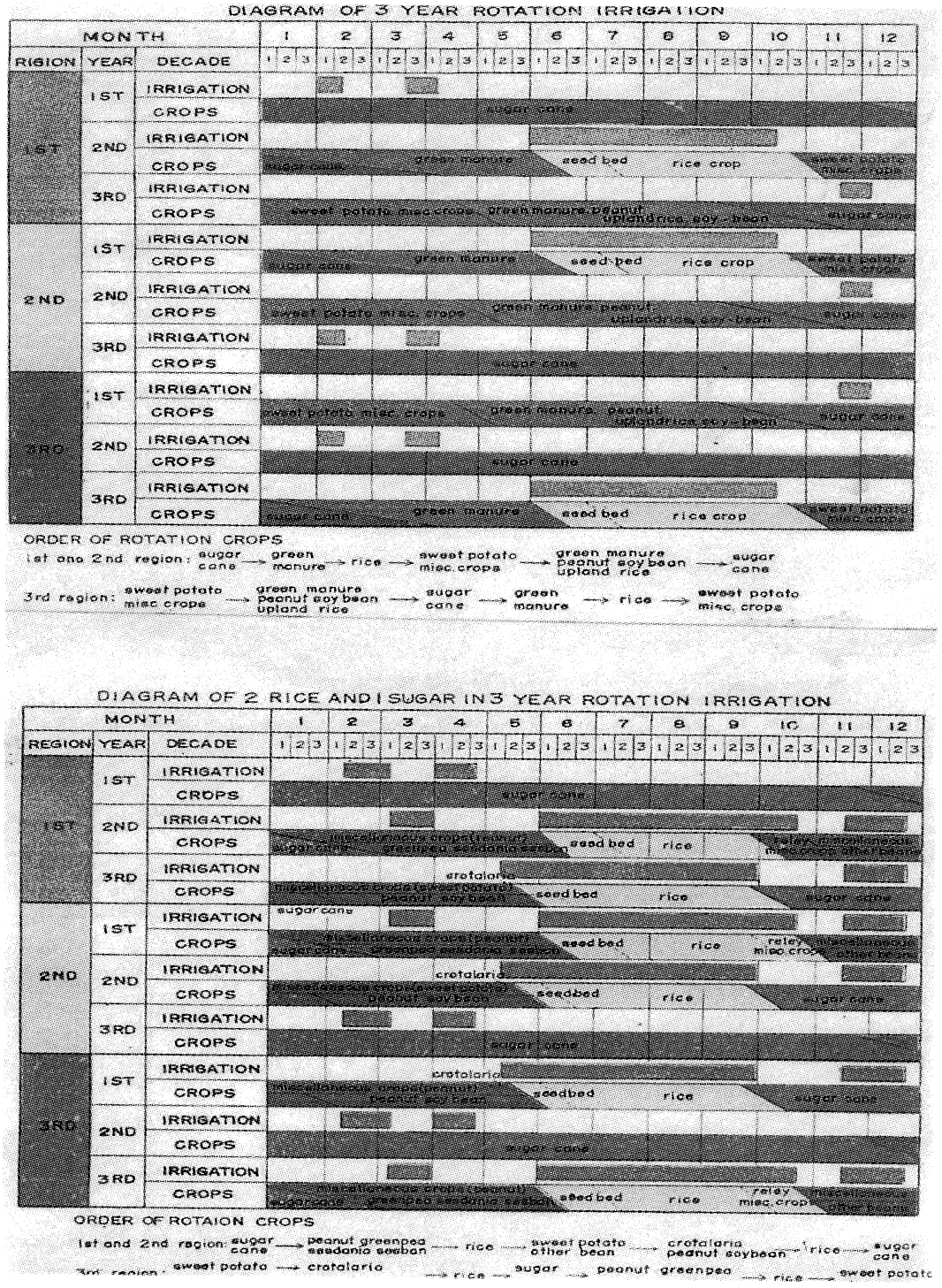


Fig. 3 Diagram of One and Two Rice Crops Rotational Cropping Pattern

Miscellaneous crops, would receive only the surplus water whenever is available, or frequently no irrigation at all. The next year, the second sub-unit would be given water to grow rice; the third to grow sugarcane and the first to grow miscellaneous crops, and so on. Thus the differential water supply is

applied to the three sub-units on a three-year rotation basis.

3.4 Supportive Measures for Rotation Cropping Pattern

1. Organizing Water Groups

To ensure the success of rotation cropping, Water Users' Groups and Sub-groups were organized according to their units and sub-units. The main task of the organization includes: A leader for each water group would be elected through common election for a three-year service term; and three sub-group leaders would be assigned by the elected group leader. The responsibility of water group leader would mainly serve as the following:

Conducting fixed term and temporary water group meetings for discussing irrigation and cropping schedule related affairs;

Conveying farmers' view regarding irrigation, cropping pattern, water fee and matters relevant to the system controllers i.e. the irrigation association;

Conveying the message from the irrigation association to the farmer; and

Other relevant matters entrusted by the Government or the irrigation Association.

2. Government's Intervention

In the early stage of the implementation of rotational cropping pattern, the willingness of farmers to follow was limited. The Government had provided a strong support and intervention to make sure the success of rotational cropping pattern. For the most cost effective the use of water at that time, the Government usually gave the first priority to paddy rice, the second to sugarcane, then upland crops. It has taken about six (6) years on trial-and-error approach to make the arrangement of rotation cropping pattern to be mature.

3.5 Modifications on Rotation Cropping Pattern

The preliminary rotational cropping patter was firstly operated in 1927 during Japanese colonization. After World War II, Taiwan was restored to the Republic of China in 1945; since then, more water resources were developed to produce more rice to meet the increase in populations. As of the now, there are six kinds of cropping pattern prevailing in Taiwan. They are:

1. Double Paddy Cropping Pattern: rice grows in the both wet and dry seasons each year.
2. Single Paddy Cropping pattern: rice grows only in wet season each year.
3. Two Paddy Rice Crops Each Two Years Pattern: rice grows in wet season in the first year and another rice crop grows in dry season the next year.
4. One Rice Crops in Three Years: rice grows in the wet season once out of three years.
5. Two Rice Crops in Three Years: rice grows only in wet seasons twice out of three year; and sugarcane or upland crops during the remainder of three years.
6. Modified Two Rice Crops in Three Years: rice grows once in wet season and other in the dry season of another year out of three years.

IV. Rotational Irrigation

In general, water delivery for irrigation in Taiwan is not based on the demand of individual farmers. Irrigation usually follows a precise schedule recognizing farmer needs. The method is called rotational irrigation. A conventional continuous irrigation method, whenever water resources permit, the paddy rice field is usually filled with water from transplanting to ripening. This practice might waste much water through deep percolation, evaporation and reductions in the use of effective rainfall. Experiments conducted at several paddy fields for more than six (6) years had demonstrated that an increase in the yield of paddy production could also be achieved.

4.1 Basic Concept of Rotational Irrigation

Rotational irrigation is an intermittent application of irrigation water at a regular time interval and with specified water depths. The amount of water applied to each cycle of the rotation is based on the actual need of crop's consumptive use and irrigation requirement according to the different growth stages of paddy. This method will result in one or two days without water standing on the field. It permits a periodical aeration of the root zone, which is considered to be beneficial to a better growth and production of paddy rice. This concept and practice in Taiwan had already prevailed about two hundred years ago.

4.2 Advantages of Rotational Irrigation

The above-mentioned experiments and demonstrations found that the rotational irrigation compared to the conventional irrigation has the following advantages. They are:

1. Rotational irrigation has shown to achieve water saving by 20-25 percent as compared with conventional continuous irrigation in the long-term.
2. Most cases indicate a higher yield with rotational irrigation.
3. Rotational irrigation decreases irrigation disputes and helps the development of cooperative atmosphere and order in the practicing irrigation in the rural areas.
4. Rotational irrigation encourages the use of the common irrigator, by which the farming time on irrigation by individual farmer can be saved resulting in farming efficiency.
5. Rotational irrigation provides the management's more opportunity to have a better handling drought situations and the rapid fluctuation of water resources.

4.3 Planning of Rotational Irrigation

1. Paddy Rice Growth Periods

Growing season and Irrigation period of Paddy Rice in those areas of Taiwan where two crops of rice are grown, the first crop is grown during the spring and summer, and the second crop in autumn and early winter. In those areas where only one crop of rice is grown, in the rainy season from June to September, it is called the intermediate crop. Generally speaking, the first crop rice has a longer growing period and a higher yield than the

second crop or the intermediate crop rice. The length of growing period also differs with the variety of rice. The local variety, Tsailai rice, usually requires a longer growing period than the imported variety, Ponlai rice. Research has shown that the growing periods in the main field, from transplanting to maturity, for the first and second crops are 105 to 115 days for Ponlai variety, and 110 to 120 days for Tsailai variety, respectively. The growing periods in the seedling bed for the first and second crops are 15 to 35 days for Ponlai, and 30 to 45 days for Tsaili, respectively.

2. Irrigation Water Depths in Various Paddy Growth Periods

Based on these main activities of rice farming, the irrigation of paddy rice may be classified into the seedling bed, land preparation and main field stages. The need of irrigation water depth in each stage is:

Seedling Bed: Seedling bed irrigation, for an area only 1/30 to 1/25 of the main field is irrigated with a design flow of 0.008 m^3 each rotational area of 50 ha;

Land Preparation and Transplanting: The irrigation depth for land preparation varies with the workability and permeability of the soil upon saturation; 150 mm is considered to be necessary for sandy soil, and 100 mm depth of water for clayey soil respectively; and

Main Field: Daily irrigation depth for main field stage varies from 14 mm to 24 mm for sandy to clayey soils. The normal irrigation depth varies mainly with the type of soil, because the soil texture induces more variability in water consumption than do the climatic factors. The percentage of soil particles below 0.005 mm has been selected as an index to link soil types and the normal irrigation depth. From sandy to medium clayey soils with the percent fines ranging from 8 to 40, the normal irrigation depth ranges from 7.0 mm to 16.0 mm per day. With these data, the normal irrigation depths of three major soil types could be specified for different 10-day periods. Table 1 shows an example of calculating the details of irrigation requirements each different growing stages of paddy. The exercise illustrated in Table 1 appears complicated, but it would be done once for each crop and each different season; then the result would be applicable for another year. The more complex tasks of the planning for the rotational irrigation is calculating the predicted effective rainfalls for each 10-day period. The last 5 years' rainfall record would be main base for this analysis and prediction, and thus the prediction of effective rainfall is the important regular exercise for each season. During the actual water application, the predicted effective rainfall would be reduced from the irrigation requirement s shown in Table 1. In another words, the actual depth of water application the balance of irrigation requirement and predicted effective rainfalls.

4.4 Practicing Rotational Irrigation

1. 10-Day Irrigation Interval

Based on practical considerations, an average of variation in every10-day period is used as the time interval for irrigation water

application; i.e. irrigation water requirement for the system changes only every 10-day period. Within each 10-day period, discharge for canal system remains constant through the 10- day period. Furthermore, each 10-day requirement is used to express as a percentage of the normal irrigation depth on the main field. A normal depth of 100 percent for the 1st, 8th and 9th 10-days; 110 percent for 2nd and 5th 10-days; 80 percent for the 3rd and 4th 10-days; 110 percent for the 6th and 7th 10-days have been adopted successfully in the Chianan Irrigation Association. The example of this planning is shown in Table 1.

2. Water Delivery Schedule

To prepare the water delivery schedule, a normal speed of seedling transplanting of about two hectares per day is assumed. For a standard rotation area of 50 hectares, 25 days would be required to complete transplanting operation. To provide a water delivery schedule precisely corresponding to the varying irrigation requirements of different ages of seedlings transplanted in small and scattered paddy plot is tedious but important. For this, a survey of actual land utilization and irrigation status including details such as the rotation unit and irrigation system; the irrigating and transplanting areas; the previous and intended crops; the intended date of seedling and transplanting; and the name and address of the tiller are essential, both for pre-irrigation planning and for post-irrigation evaluations. Various charts and methods have been designed to simplify the data collection and computation procedure. For the preparation of the overall water delivery schedule for rice irrigation, the computation of weighted irrigation requirements, considering the factors of soil types, crop growing stages, and the pre-decided transplanting schedules, have been adopted successfully by Chianan Irrigation Association. An example is also presented in the Table 1.

3. Management of Water Delivery System

Successful operation of a canal system practicing rotational irrigation depends not only on proper management of the conveyance system that brings water from water source to the head gate of the distribution system, but also on proper management of the irrigation water within the distribution system. To coordinate the conveyance and distribution system, a series of forms have been designed for recording and reporting the daily irrigation activities. The management system for water delivery is illustrated in Fig 4.

Table 1. Calculation of Irrigation Water Requirement

Growing Stages of Rice	10-Days After Transplanting	Equations for Weighted Irrigation Requirement Calculation	Amount of Weighted 10-Day irrigation Requirement(mm)	Weighted Daily Irrigation Requirement (mm)
Start of transplanting	--	$1/2P+1/2I_0$	1/2*112+1/2*64=88.0	8.8
Continuing of transplanting	1st	$1/3P+1/2I,+1/3I_0$	1/3*112+1/2*64+1/2*64=90.6	9.1
Initial tilling	2nd	$1/6P+1/6I_0+1/3I_1+1/2I_2$	1/6*112+1/6*64+1/3*64+1/2*58=79.7	8.0
Effective tilling	3rd	$1/6I_1+1/3I_2+1/2I_3$	1/6*64+1/3*58+1/2*53=56.5	5.7
Highest tilling	4th	$1/6I_2+1/3I_3+1/2I_4$	1/6*58+1/3*53+1/2*53=54.0	5.4
Young-heading forming	5th	$1/6I_3+1/3I_4+1/2I_5$	1/6*53+1/3*53+1/2*58=55.5	5.6
	6th	$1/6I_4+1/3I_5+1/2I_6$	1/6*53+1/3*58+1/2*71=63.6	6.4
Normal heading forming	7th	$1/6I_5+1/3I_6+1/2I_7$	1/6*58+1/3*71+1/2*71=69.2	6.9
Milky-ripening	8th	$1/6I_6+1/3I_7+1/2I_8$	1/6*71+1/3*71+1/2*64=67.7	6.8
Starchy-ripening	9th	$1/6I_7+1/3I_8+1/2I_9$	1/6*71+1/3*64+1/2*64=65.0	6.5
Yellow-Ripening	10th	$1/6I_8+1/3I_9$	1/6*64+1/3*64=31.7	3.2
Maturing	11th	$1/6I_9$	1/6*64=10.7	1.1

Remark: this table is an example for loamy soil.

4. Water Delivery Management

The management of water delivery from the irrigation plan, to the water conveyance, to the water distribution is the duty of employees of the Association; actually applying water to the each plot of land is usually the job of the common operator or common irrigator. The Common operators, hired by Working Station, are responsible for actual water distribution including: informing each landowner about the irrigation schedule or irrigation timetable; carrying out the water application to each plot of land in accordance with the irrigation schedule planned by employees of the Irrigation Working Station; maintaining the farm ditches in good condition; any other assignment concerned with water distribution.

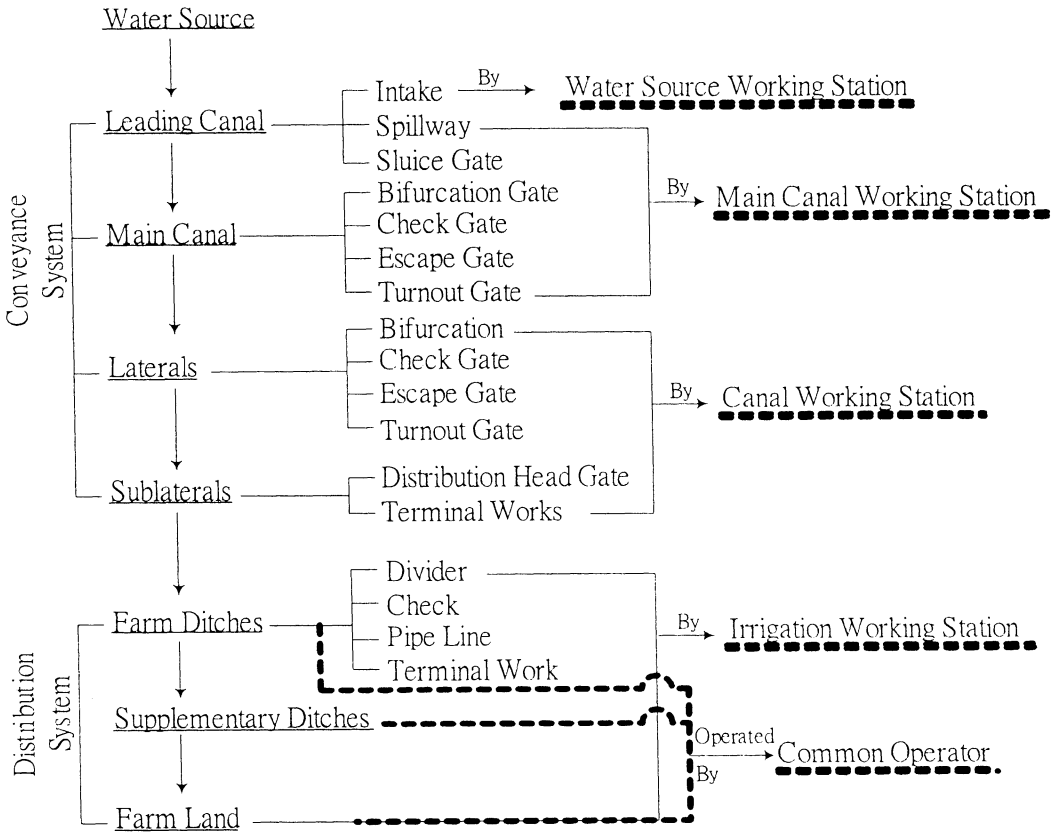


Fig4. Irrigation Facility and Its Management System

4.5 Water Applications

1. Water Distribution to Land

Previously, the main objectives of irrigation were essentially limited to the production of rice, while only a minor part of water has ever been used for up-land crops irrigation. Flood irrigation is the only method of water distribution used for paddy rice on the entire island. There is no special skill developed for the flood irrigation of paddy rice. Paddy rice areas generally have slopes from 0-3 percent, and no difficulty has been experienced with flood irrigation of paddy. Actual operation is simple in principle; by penetrating several pipes through the dike of the farm ditches; irrigation water would be diverted to the field by removing the plug of pipes of the bank of ditch.

2. On-farm Water Distribution Systems

About two-third of the total irrigation area has been consolidated under the Land Consolidation Project. The shape of farm is regular and the length of runs varies from 100 to 150 meters. Each plot of land in such area is adjacent to irrigation; drainage ditches; and farm road. Water distribution is easy and simple. However, in the area without land consolidation, the farm shape is irregular and the length of run varies from 50 to 200 meters.

Some of them must be served by water passing through several pieces of lands. This has been a serious problem for a long time. Conflict and disputes often occurred when permission for by-pass is not obtained. The quantity of irrigation water is measured only at head gate of the distribution system, the amount applied to each plot is determined by accounting the application time in proportion to the area of plot. The average size of plot is about 0.3 hectares.

3. Upland Crops Water Applications

For upland crops, furrow irrigation is extensively adopted, and it is especially suitable for the row crops grown in level rice paddy during the dry season. With limited water supply, a better drainage system for removing excess irrigation water at the ends of rows is not used in this area; all water applied to the furrow is supposed to be stored in the soil. The irrigation water depths for various crops, 90mm for sugarcane and 70 mm miscellaneous crops, measured at the head gate of the distribution are considered to be the most practical water depth of the sufficient water in the downstream portion of the furrow.

4.6 Adjustments of Irrigation Plan in Case of Drought

Adjustment of the water distribution schedule, when serious drought spelled out, must be considered to reduce the amount of water in several less important stages and to fulfill the requirements at critical periods, such as the seedling bed stage, land preparation, transplanting, head forming, etc. Intensive utilization of effective rainfall through strengthening and heightening of the field dikes should also be considered. Different adjustments are specified for canal systems with and without storage facilities as follows:

1. Reservoir Systems

In general, prolonging the rotation interval without a change of water depth is the most acceptable to farmers and suitable for a large reservoir system. Detailed considerations for the different cases are given below:

Drought before irrigation: Water should be reserved in the reservoir for full irrigation of the stages of seedling nursery to seedling transplanting, then prolonging the rotation interval for main field irrigation or intermittent application of irrigation water for the seedling bed should be carefully considered according to the remaining water and predicted inflow; and

Drought developed during main field irrigation: When the water in the reservoir is found inadequate to serve two cycles of rotational irrigation, prolonging the rotation interval will be considered immediately.

2. Non-Reservoir Systems

Drought before irrigation: When the available river flow is found to be less than 80 percent of the normal irrigation requirement, the laterals of the whole irrigation system should be arranged into groups to permit group rotation. Different combinations of lateral groups and intermittent intervals may be attempted to achieve an irrigation schedule consistent

with the estimates river diversion; and

Drought developed during main field irrigation: Different arrangements of lateral groups and irrigation intervals should be developed to meet different degrees of flow reduction. For the convenience of calculation, a simplified equation is listed for reference:

$$T = \frac{0.11574 A H}{Q - S}$$

T: Rotation interval, in days;
A: Irrigation area of each group, in hectares;
H: Irrigation depth applied, measured at the distribution gates, in meters;
Q: River discharge in m^3
S: Conveyance losses to the distribution gate, in m^3

$$\text{Constant } 0.1157 = \frac{\text{10,000 square meters in ha.}}{\text{86,400 seconds in a day}}$$

V. Relaxing Practice of Rotation Cropping and Irrigation

5.1 Economic Importance of Paddy Rice at Fading

In the wake of Taiwan's economy started to move toward industrialization, the share of GDP in agriculture kept falling from 32% in 1952 to 1.91% in 2001. Table 2 shows that the percentage of contribution of paddy rice to the total Gross Domestic Products (GDP) was falling from 1.9% in 1985 to 0.51 % in 2001. This fact explicitly indicates that the commodity economic benefit of paddy rice has gradually lost it competitive advantages in sharing the land and water resources to the non-agricultural sectors.

Table 2. Paddy Rice Contribution to Total GDP Units: %

Year	Agriculture Contribution To GDP	Rice's Contribution to Total Agriculture	Rice Contribution to National GDP
1985	5.8%	32.6%	1.90%
1990	4.2%	33.9%	1.42%
1995	3.6%	30. 7%	1.11%
1997	2.7%	29.4%	0.80%
2001	1.91%	26.7%	0.51%

Sources: data from "Basic Agricultural Statistics, C0A. 1986—2001";
and result analyzed by Ko & Chun , AERC Feb. 2003

5.2 Relaxing Intensity of Practicing

From macro economic points of view, the more paddy rice produce, the more national economic losses would be induced. The practice of intensive rotational cropping and irrigation no long requires all the time. The actual practices for both depend on the following situations now:

1. Rotational Cropping Pattern

The decision on which crops to grow each season ultimately rests with the farmer himself; but the farmer accepts that the water supply constraint imposed by the irrigation association. The decision of farmers on cropping pattern adopted usually based on many factors and they should accept the result of decisions as below:

Farmers' decisions on cropping pattern may base on crops' price stability, labor requirement and susceptibility to damage by typhoon, heavy rains inundation and strong wind; and

Farmers in rotation areas display more independence and diversity in their cropping pattern decision than farmers in double paddy areas.

2. Rotational Irrigation

When the wage rate of labor is becoming dearer, the intensive rotational irrigation is an extremely expensive practice. Most of cases showed that the profit of such irrigation could not offer to pay for this kind of practice. As such, the practices of rotational irrigation are generally relaxed depend on the availability of water and the profits of irrigation. However, it does not mean that Taiwan has already totally abandoned the practice of rotational irrigation. It has kept flexible as following:

The intensive rotational irrigation still maintains in the areas where deep ground water is .the unique water resources for irrigation;

Different intensities of rotational irrigations are still prevailed whenever drought spells out; and

The potential of practicing intensive rotation irrigation still exists in terms of the hardware facilities or the software of knowledge on know-how.

VI. Conclusions

The lesson learned after reviewing the practice of rotational cropping pattern and rotational irrigation in the last forty years in Taiwan, it strongly leads to the conclusions as following:

6.1 Equity Implications

Observing that, officially designated cropping pattern is so often ignored by farmers now; and the facilities built and supplicated water management skill developed for practicing intensive rotational irrigation were found under utilized and partially deserted. This fact does not necessarily lead to the conclusion that, when the contemporary responsibilities were over, and thus they should be totally abandoned now. On contrary, the spirit of equity in allocating limited water to the farmer demonstrated from the both practices is the main supporter

for the water controller to convince water users that they are being treated equally at sharing limited water so long as the rotational cropping and irrigation is still practicing.

Awareness of the fact that, equity in water allocation and strictly following designated cropping pattern do not guarantee the farming profits of individual farmer or national income would be the optimal, but they still prefer this arrangement and are willing to take their own risk. The Government also encourages farmers to diversify more their cropping instead of following the designated cropping pattern. This implies that once farmers are treated equally in sharing the water, they accept whatever the result of farming which they made decision by themselves.

A more precise speaking, the rotational cropping pattern implies a long-term equity; and the rotational irrigation, a shorter term in sharing the uses of water.

1. Long Term Equity

Regardless of the existing situation that fewer farmers strictly follow the officially designated cropping pattern, they still accept the arrangements of water allotting schedule in accordance with the designated cropping pattern, but they do not necessarily following the cropping which they receive the water. For instance, when they are scheduled to receive sufficient water to grow paddy rice, they may or may not grow paddy rice. If they grow any non-paddy crop and have used less water, which they owe, they would not receive any compensation for the water they do not use. It is therefore that the actual meaning of designated cropping pattern remained now is the tool for equitably sharing water in the long terms of season and amenity.

2. Short Term Equity

In the wake of participation in World Trade Organization (WTO) permitted in January 2002 for Taiwan, paddy rice is no longer the most profitable crop regardless of domestic price support program still available, but the paddy rice fallowing program is equally attractive to the farmer who does not have sufficient capability of farming in the field. Particularly, in the rotational cropping area, more than 30 per cent of farms do not grow rice although they are entitled to grow. Consequently, in the normal hydrological year, the amount of water available for irrigation would be often more than the field needs, therefore, the previous strictly rotation irrigation is no long required. Farmer would be in the first priority to use the water to irrigate upland crops if the land is in turn to grow rice. If additional water still avails, they use their water to irrigate any crop in the areas where are not in turn for irrigation. This practice strongly implies that the spirit of short-term equity in sharing water still remains and sustains now.

6.2 Future Prospects

The prevailing national agriculture policy has run from development before 1980s into compensation now. The goals of policy are mainly at: maintenance of

food security, avoidance of widening income gaps between the rural and urban, production diversification for reducing the agricultural subsidy, preserving ecosystem and biodiversity. To meet the requirement, continuous modifications on the uses of irrigation water would not be avoided; and irrigation sector is ready for the modification.

A more intensive rotational cropping and irrigation might have the potential to be recovered to some extent in the future, if the agriculture sector is pressed to release certain amount of water the to industry and domestic water supply sectors, and the agriculture sector is not allowed to further reduce the cultivation areas. As such, the facilities and technical know-how for practicing intensive cropping and irrigation should not be arbitrarily deserted.

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The 3rd APEC Workshop on Sustainable Agricultural Development

Session 3

Cropping System

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Multiple Cropping as a Strategy in Sustainable Soil Management

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Introduction

Farm land sustainable management are processes to grow crop aiming at the use of renewable nature resources to provide food, income and livehood for the need of mankind not in current society but also in coming generations. The system concern the maintainence of ecosystem and the maximum Agricultural economic productivity (Cohen et al., 1991). However, in commercial agriculture management, a stable production and high productivity cropping system are adapted in farm land and natural resources using. Those systems always impact farmland ecosystem adversely. In modern agriculture practice, monoculture without rotation induce soil degradation severely. How to maintain the productivity and vitality of farm soil becoming an important issue in sustainable agriculture management. According to Damask et al (1991), the following goals are searching for agricultural production and sustainable management. There are a). maintain or enhance production/service, Productivity, b).reduce the level of production risk, Security, c).preserve the productive potential of natural resources and prevent degradation of soil and water qualities, Protection and d).be economically viable, viability and be socially acceptable, Acceptability.

Cropping pattern is the yearly sequence and spatial arrangement of crops, or of crops and fallow on a given farm. And cropping system is the cropping patterns used on a farm their interactions with farm resources, other farm enterprises, and available technology that determine their make up. There are many cropping system practice in the world including swidden cultivation, monocropping, multiple cropping and fallow or setaside. Monoculture is the repetitive growing of the same crop on the same piece of land, while multiple cropping is the intensification of cropping in time and space dimensions, growing two or more crops on the same field in a year. The cropping patterns of multiple cropping can be intercropping such as mixed, row, strip or relay cropping, and sequential cropping such as double, triple, quadruple or ratoon cropping (Table 1). Strategies in multiple cropping emphasis on time and space arrangement to maximumize crop productivity, so, multiple cropping system provide high efficieny in farm land use (Howard and Lessman, 1991). In areas of the world where multiple cropping is a common aspect of agroecosystem

management, productivity generally is more stable and constant in the long term (Gliessman and Amador, 1979 and 1980).

In considering use multiple cropping as actual alternatives we need to understand thoroughly the biological and agronomic basis responsible for the observed response, as well as the advantages and disadvantages to their use.

The advantages of multiple cropping are summarized as follow: 1).reduce the risk of field losses to drought, insects and diseases, 2). obtain a better use of vertical space and time in limited farmland. 3).legumes (as well as a few other plant families) are able to fix and incorporate nitrogen into the system, 4).diversified products are produced to help balance diet for farmer, 5).higher planting density and heavier mulch cover aids in weed control, avoidance or reduction of surface erosion. 6).improved soil structure, avoiding the formation of a "hard pan" and promoting better aeration and filtration 7).better opportunities for biological control of insects and diseases.

The disadvantages of multiple cropping systems are 1).competition between plants for light, soil nutrients and water, 2).it is difficult to harvest one crop without damage the other, mechanize and incorporate a fallow period in or into the systems 3).possible over-extraction and loss of nutrients and allelopathic influence between different crop plants.

Change of soil fertility under cropping patterns

Soil is an essential part of the biosphere and the basis for crop cultivation. Soils as natural-historical body have two alternative ways of development, 1).natural or, 2).anthropogenic. For the natural development of soils a period of one hundred years is immaterial and may not cause radical changes of soils and soils cover. More important way of development is the anthropogenic one. And this way is negative and leads to the violation of natural processes, degradation and final destruction. An improper cultivation especially fertilization results in the influence of different extents on soils. Sustainable soil management is the fundamental basis for sustainable agriculture.

As world population has increased, increasing the need for agricultural production, continues to stimulate more intensive agricultural investigation in a search for more productive alternatives. By the types of genetic manipulation that gave us such rapid and impressive yield increases during the "Green revolution". However, the high yielding varieties required high levels of fertitizers, water use and pest control. In order to uphold crop yield and increase profit, a monocropping system with large scale cultivation, heavy chemical fertilizers and pesticides application and huge and heavy farm machinery field operation were developed. The system impact the agroecossystem diversely. chemical fertilizers, pesticides, herbicides and farm machinery become the main materials for agricultural production (Rappaport, 1971).

For the past 50 years, we learned that the producer selected their crops to grow and their cultivation practices by considering how much profit they can get and neglecting the influence of the cropping system in farm land ecosystem. The

farming practices are close related to types of farm land use. According to Salterm et al (1941), continuous corn or wheat had detrimental effects on soil organic and nitrogen content (Table 2). Farm land fallow in high cultivated frequency, high cropping index area may not be a good practices of sustainable soil management. For example, in rain-forest area or rain-season, the fallow land suffer from increasing soil loss and run-off due to exposed surface soil without any mulch (Table 3). So, in the crop growing processes, from the soil protection point of view, no matter which cropping pattern you have taken, the most important thing you must consider is to grow or leave crop covering on soil surface. Soil losses and run off problem were more seriously in continuous plot than rotation (multiple cropping) plot. Since the nutrient losses are close related to soil losses, the nutrient losses also more in continuous plot (Table 4).

In order to meet the market demand or to provide the agriculture commodity year around, the types of large scale continuous single crop cultivation in specific area were developed. However, one harvest always get limited yield. So, the farmer always grow many same crops in the same land per year. They applied heavy fertilizers, pesticides, used a lot of water and huge farm machinery. Soil degradation were found in those farm land. There are 5 to 7 millions farm desertification in the every year (FAO, 1995). Soil degradation of farm land had three major characters 1).degraded soil physical, chemical and biological properties by lowering down their productivity. 2).erosion reduce soil volume and mass, losing the physical size of soil ecosystem 3).accumulated specific chemicals in soil. For the first soil degradation process comes from a).excess or improper tillage induce soil compaction and humus shortage, b).improper crop grown or fertilizers and pesticides application make less soil microbial population and diversity. c).continuous corn and cassaw deplete soil nutrients in long time growing. The second process comes from a).continuous single crop growing in same piece of farm land, b).strip farming c).excess tillage or plowing, d).clearing tilled or crop residues removal, e).development of new land. While the third process comes from a).the move of soluble salts upward to the soil surface becoming soil salinization; b).nitrate leaching or crop or residues removal and excess fertilization, c).chemicals addition in growing period, those chemicals can not be absorbed or decomposed and then contaminated the soil. For the all above mentioned soil degradation processes are easily found in continuous single crop long term growing system. Currently, the development and use of continuous cropping system may resolve food shortage problem temporaily. But system impact farm land agroecosystem adversely. Eventually, a stable and sustainable agriculture production will be destoryed by inducing quantities and qualities of soil degradations.

Effect of multiple cropping on agricultural production and farmer's revenue

Current agricultural management in farm land and resources use take stable

and higher yield as goals for agriculture production. In general, two types (mono or multiple) of cropping system are seen. In many modern countries, the monoculture is more popular than the multiple cropping. However, in considering the sustainability, the multiple cropping is better than the mono. Because the multiple cropping need less inputs such as chemical fertilizers, pesticides and farm machinery. 1).higher crop diversity in cropping system reduce or avoid the occurrence of harmful. insects or diseases damaged(Hammod and Jeffers, 1990; martin et al., 1989), 2).by using the root characteristics such as shallow or deep root distribution in soil to absorb and use nutrients in soil lager. and water. incorporating legumes in cropping system increase N2-fixation and reduce the amount of nitrogenous fertilizer application. 3).multiple cropping emphasis rotation or intercropping, left more crop residues or roots on soil. and increase soil organic matter content indirectly. Reduce the frequency of tilth and prevent soil crust formation.

From the point view of producer, multiple cropping systems increase the value and income of agricultural production (Beuerlein, 2001; Craner and Cucero, 1992). According to Ohio State University the roots of wheat penetrating soil to the depth 35-47 inches, while soybean 23-35 inches in relay cropping experiment (Table 5) (Taylor, 1965; Hagan and Stewart, 1972). The two crops can be intercropping although the yield of wheat decreased and harvesting time prolonged slightly by the influence of soybean but the total yield of two crops were higher the crop grown as continuous cropping individually (Table 6). The intercropping also had better profit (Talbe 7). Indicating a proper combination crops growing could increase the values and profits in multiple cropping system.

Multiple cropping systems in Taiwan

Taiwan is situated in a subtropical and tropical climate where the warm temperature, high rainfall and abundant sunlight are suitable for growing crops the whole year around. During the past 300 years, an intensive farming system with rice crop as basis and four or five crops year was established. Three major multiple cropping patterns were popular on paddy fields in early 1960's, 1).rice and crops with a short growth period, thus, 1st crop of rice follow-up a summer crop, then 2nd crop of rice, and finally winter crop, 2).rice and sugarcane under normal conditions, thus, 1st crop of rice follwow-up by a summer crop then 2nd crop of rice, and finally winter intercrop and relay interplanted sugarcane 3). Rice and sugarcane when irrigation available in only one of three years, thus, 1st crop of rice followed by summer crop, then winter intercrop and relay interplanted sugarcane, and finally, ratooned sugarcane with winter intercrop. At the same time, an intensive farming systems in upland with various crops also developed. sweet potatoes, corn, vegetables and fruits were grown. During 1960s, multiple cropping index of Taiwan reached 1.90, one of the highest in the world.

In order to know the effect of different crops grown in multiple cropping on the production soil fertility and farmer's income, field experiments were carried out in Tainan and Hualein District Agricultural Improvement Station. Results of Tainan showed that the grain yield of rice were not affected (Table 8). While sorghum and corn had better yield in legume included systems. (Table 9 and 10). Soybean got more yield after rice (Table 11).

For the net income, the rice-soybean-corn got the best, then rice-sesbania-corn and soybean-rice-corn were followed (Table 12).

As for the changes of soil fertility, we found soil fertility in Tainan were getting better such as organic matter phospbrous, potassium content increased after the 10 years experiment.

Discussion and conclusion

Reducing the inputs of man-made materials and the operation frequency of heavy farm machinery in farm land are the final goals purchasing in using multiple cropping systems as a strategy in sustainable agricultural management. Multiple cropping can avoid the depletion of soil resources. By chosing suitable crop combinations. Growing period and types of cropping system increase soil productivity, water use efficieny, and insects and diseases controlling, we may bring down the processes of soil degradation which are accelerated by monocropping.

On the basis of crop cultivation, many selections may take several argicultural technologies or practices including 1).land preparations, crop residues management and tillage, 2).chosing crops and varieties. 3).growing period and types of planting 4).fertilizers and their application, 5).pest controlling. Although multiple cropping systems including intercropping or rotation are better than monocontinuous cropping in maintainence of farm land agroecosystem, recycling agricultural wasters and usage of natural resources. However, monocropping could better agricultural economic efficiency of the in short term.

Monocropping system are characteristic with single crop, large scale farming and year around continuous cultivation, simplify the crop planting and field operation, applying chemical fertilizers and pesticides to supply nutrients and controlling insects and diseases. It is also easy to use huge, high efficient farm machinery to substitute man power for reducing labor cost. Those methods are making monocropping system reach high yield production in short period. However, after several decades monocropping have degraded soil with low productive found in many farms. Among them, improper or excess pesticide application make the occurrence of insects and diseases more frequent and difficult to control. High rate chemical fertilizer application resulted in soluble salts accumulation which contaminatsed or toxificed the soil. The single continuous growing crop depleted plant nutrients in soil. In order to sustain farm land management in crop producing several strategies are suggested:

A better use of vertical space and time on farm land before crop cultivation, especially in soil mulch and cover to prevent surface soil erosion.
Maintain the field crops diversity highly. Consider the possibilities of mechanization in rotation or intercropping systems.
Recycle plant nutrients completely. Return plant residues to field for nutrients and soil surface protection.
Increase soil biological activities. Incorporate legumes in multiple cropping systems to increase nitrogen fixation.
Maintain and rebuild soil matter content.
Better combination of crops to be use in sequential. mixed or relay cropping.

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Table 1. Multiple cropping system definitions.

Multiple Cropping	Intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.
1.Sequential Cropping	● Crop intensification is only in the time dimensions. ● Growing two or more crops in sequence on the same field per year. ● The succeeding crop is planted after the preceding crop has been harvested. ● No intercrop competition. ● Farmer manages only one crop at a time in the same field.
a) Double Cropping	Growing two crops a year in sequence.
b) Triple Cropping	Growing three crops a year in sequence.
c) Quadruple Cropping	Growing four crops a year in sequence.
d) Ratoon Cropping	Cultivation of crop *regrowth* after harvest, although not necessarily for grain; allows multiple, separate harvests.
2.Intercropping	● Crop intensification is in both time and space dimensions. ● Growing ywo or more crops *simultaneously* on the same field. ● There may be intercrop competition during all or part of crop growth. ● Farmer manages more than one crop at a time in the same field.
a) Mixed Intercropping	Growing two or more crops simultaneously with no distinct row arrangement.
b) Row Intercropping	Growing two or more crops simultaneously where one or more crops are planted in distinct rows.
c) Strip Cropping	Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation, but narrow enough for the crops to *interact* agronomically.
d) Relay Cropping	Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest.

Source: Papendick, *et. al.*, 1976

Table 2. Organic matter and nitrogen content of unfertilized plots at Wooster, Ohio.

Cropping-system	Begun Year	Analyzed Year	Organic matter (lb/acre)	Nitrogen (lb/acre)
1984		1894	35,050	2,176
Corn, oats, wheat, clover, timonthy	1984	1925	26,700	1,546
Continuous corn	1984	1925	12,730	840
Continuous oats	1984	1925	22,800	1,425
Continuous wheat	1984	1925	22,050	1,315
Corn, wheat, clover	1987	1925	29,500	1,780

Source: Salter, *et. al.*, 1941

Table 3. Average annual rainfall, runoff , and soil loss from crops

Cropping-system	Years of record	Rainfall (in.)	Runoff (in.)	Soil loss (t/acre)
Continuous fallow	1960-1966	48.53	11.84	5.14
Continuous peanuts	1951-1958	42.92	2.88	1.23
Continuous corn	1955-1966	47.05	1.24	0.77
Meadow (bermudfrass and clover)	1951-1954	43.66	0.35	0.34
Three-year rotation	1951-1966	46.20	1.83	0.98
Oats	1951-1966	46.20	1.20	0.51
Peanuts	1951-1966	46.20	1.83	1.32
Corn	1951-1966	46.20	2.47	1.12
Four-year rotation	1952-1966	46.09	1.96	0.71
1^{st} year meadow	1952-1966	46.09	3.11	0.92
2^{nd} year meadow	1953-1966	46.33	0.31	0.46
Corn	1952-1966	46.09	0.80	0.56
Peanuts	1952-1966	46.09	1.65	0.91

Source: Thomas, *et. al.*, 1969

Table 4. Average annual rainfall, runoff , and soil loss by cropping treatment.

Treatment No.[a]	Cropping treatment	Slope (%)	Row direction[b]	Rainfall (in.)	Runoff (in.)	Soil loss (t/acre)
1	Fallow	7	(C)[c]	55.71	18.35	60.43
2A	Cotton continuously	7	A	55.71	6.33	12.28
2B		7	W	55.71	9.84	21.86
3A	Corn continuously	7	A	55.71	4.54	4.02
3B		3	W	55.71	6.54	2.40
3B		7	W	55.71	7.03	12.11
3B		11	W	55.71	2.40	20.90
4A	3-year rotation of					
	1st costal bermudagrass	7	(C)	54.78	2.42	1.99
	2nd costal bermudagrass	7	(C)	54.78	1.78	0.16
	Corn	7	W	54.78	4.42	4.43
	Rotation average	7	W	54.78	2.87	2.19
4B	3-year rotation of					
	1st costal bermudagrass	7	(C)	54.78	2.25	2.26
	2nd costal bermudagrass	7	(C)	54.78	2.74	0.19
	Corn	7	A	54.78	2.99	1.08
	Rotation average	7	A	54.78	2.66	1.17
5	3-year rotation of					
	1st tall fescue	7	(C)	56.73	5.42	0.88
	2nd tall fescue	7	(C)	56.73	2.80	0.09
	Corn	7	A	56.73	4.56	1.97
	Rotation average	7	A	56.73	4.26	0.98
6	4-year rotation of					
	1st tall fescue	7	(C)	57.56	11.04	4.05
	2nd tall fescue	7	(C)	57.56	5.07	0.05
	Corn	7	A	57.56	6.04	2.93
	Cotton	7	A	57.56	7.23	6.25

[a] Years of record: treatment numbers 1 to 3, 1961-1967; treatment numbers 4, 1962-1967; treatment numbers 5 and 6, 1961-1965.
[b] A = rows on contour ascross slope; W= rors uphill and downhill with the slops.
[c] No rows.
Source: Carreker, *et. al.*, 1977

Table 5.

Crop	Depletion of Availiable Water (percent)	Root Zone Depth (deep soil irrigation) (inches)
Alfafa	30-50	47-70
Beans, dry	50-70	23-35
Corn	40-60	29-47
Cotton	50-65	35-47
Potatoes	25-50	23-35
Sugarbeet	30-60	35-47
Grain sorghum	50-70	35-47
Sobean	50-60	23-35
Wheat	50-70	35-47

Source: Taylor, 1965; Hagan and Stewart, 1972

Table 6. Three-Year Average Yield of Becker Wheat and Union, Regal, and Williams-82 Soybeans, Wooster, Ohio.

Row Arrangement	Wheat		Soybean	
	Bu/Ac	Percent	Bu/Ac	Percent
Monocrop*	71	100	48	100
14" rows, both crops	65	91	36	74
21" rows, both crops	60	84	38	79

* Wheat in 7" rows; soybean in 14" rows.
Source: Beuerlein, 2001.

Table 7. Comparison of the Production Budgets of Monocrop Wheat and Soybeans with a Relay Crop System.

Item	Unit Price	Monoculture		Intercrop	
		Wheat	Soybean	Wheat	Soybean
Crop Yields		75	50	68	35
Receipts	**$3.00-$6.25**	**$225**	**$312**	**$204**	**$219**
Variable costs					
Seed		20	24	10	20
Fertilizer		35	19	31	13
Herbicides		4	24	4	12
Trucking, Fuel		11	11	10	9
Lub., Repairs, Misc.		31	38	30	33
Interest on Operating $		7	8	6	6
Total Variable Costs		**108**	**124**	**91**	**93**
Fixed Costs					
Labor (3 hrs)	$8.00	24	24	24	24
Machinery & Equip.		48	48	24	24
Land Ownership/Rent		80	80	40	40
Management (5% of Gross)		11	15	10	11
Total Fixed Costs		**163**	**167**	**98**	**99**
Total Costs		**271**	**291**	**189**	**192**
Return Above Costs		**-46**	**21**	**15**	**27**
Net Return / 2 Acres			**($25)**	**$42 X 2 ac = $84**	
Advantage for Relay Cropping 2 Ac.				**$109.00**	

Source: Beuerlein, 2001.

Table 8. The grain yield of rice in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average	Index (%)
A. Rice—Rice	spring	6,264a	6,641a	6,024a	6,541a	5,298b	6,569a	6,330a	7,150a	5,907a	6,972a	6,370a	100
B. Rice—Soybean—Maize	spring	6,306a	6,341a	5,599a	6,346a	5,833a	6,084a	4,971b	5,897b	5,346b	5,597b	5,832b	92
C. Rice—Sesbania—Maize	spring	6,194a	6,751a	6,037a	6,376a	6,295a	6,333a	4,786b	6,347ab	6,242a	5,861b	6,122a	96
A. Rice—Rice	summer	3,095b	4,475a	5,809a	3,517a	5,508a	4,626a	4,860a	5,820a	3,736b	5,850a	4,730a	100
D. Soybean—Rice—Maize	summer	3,583a	4,329a	5,389a	3,460a	3,733b	4,479a	2,707b	5,902a	4,333a	4,983a	4,290a	91

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

Table 9. The grain yield of maize in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average	Index (%)
D. Soybean—Rice—Maize	fall-winter	7,071b	3,223b	5,721b	5,394a	5,464c	5,336b	6,297ab	4,290b	4,985a	4,560bc	5,324c	100
B. Rice-Soybean-Maize	fall	7,956ab	3,686b	6,472b	4,620bc	6,010bc	6,041ab	5,360c	4,397b	4,944a	4,458c	5,394c	103
C. Rice-Sesbania-Maize	fall	8,483a	4,926a	9,025a	5,205ab	8,332a	6,074ab	6,485ab	4,760a	5,200a	6,415a	6,491a	124
E.Sorghum-Ratoon sorghum-Maize	fall	7,675a	4,921a	7,973a	4,310c	7,798a	5,660ab	6,064ab	4,243b	5,011a	5,271b	5,892b	113
F. Sorghum-Soybean-Maize	fall	7,522ab	3,062c	6,306b	5,400a	6,585b	6,386a	5,713bc	4,381b	4,792a	4,625bc	5,477bc	105

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

Table 10. The grain yield of sorghum in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average	Index (%)
E.Sorghum–Ratoon sorghum–Maize	spring	5,490a	5,059a	3,939b	3,996b	3,372a	4,682a	3,156a	3,530a	3,972a	4,773a	4,197a	100
F. Sorghum–Soybean–Maize	spring	6,009a	5,944a	5,708a	5,195a	3,774a	5,227a	3,626a	3,589a	4,106a	4,874a	4,805a	114
E. Sorghum–Ratoon sorghum–Maize	fall	2,825	2,333	2,017	1,688	2,129	3,164	2,504	4,111	3,472	1,828	2,614	62

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

Table 11. The grain yield of soybean in different cropping systems. (Tainan DARES)

Unit : (kg／ha)

Cropping system	Crop season	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average
D. Soybean—Rice—Maize	spring	2,365	3,523	2,638	1,747	996	2,477	2,508	960	2,383	2,479	2,207
B. Rice—Soybean—Maize	summer	1,833a	2,349a	2,314a	3,197a	1,237a	2,967a	1,533a	1,908a	850a	2,350a	1,964a
F. Sorghum—Soybean—Maize	summer	2,228a	2,985a	2,343a	2,521a	1,314a	988b	1,259a	2,474a	1,275a	2,810a	2,020a

Note : Values followed by the same letter do not significantly different (P = 0.05), according by Duncan's multiple range grouping test.

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Nitrate Contamination of Groundwater and Soil Management

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Abstract

The Japanese Government set the environmental quality standard for nitrate (NO_3) in groundwater at 10 mg N L^{-1} in 1998, based on a level considered acceptable for avoiding infant methemoglobinemia. In 1998, 6.3% of groundwater in Japan contained NO_3 exceeding 10 mg L^{-1}, with agriculture regarded to be a primary source of the NO_3 (Environmental Agency, Japan, 1999). This paper aims to define the mechanisms of NO_3 contamination of groundwater associated with soil management in arable land.

The author gives an overview of the relation between nitrogen (N) fertilization and groundwater contamination. First of all, the utilization efficiency of N fertilizers for outdoor cultivation of vegetables is usually 50% or less (Nishio, 2001; Vance, 2001). Although N fertilizer is essential for crop production, excessive N could leach out of arable soils and eventually cause NO_3 contamination of groundwater. However, conversely, excessive N is necessary as insurance in some cases, such as when there is heavy rainfall immediately after fertilization. It should be also noted that some vegetables physiologically require a high content of N in soil even at harvest.

Nitrate leaching from different fertilizers was monitored for 7 years and the data were evaluated using an N and water balance equation (Maeda et al., 2003). Excessive N from chemical fertilizers caused substantial NO_3 leaching, while compost application was promising to achieve high yields and low N leaching during a few years but led to the same level of NO_3 leaching as that in the plots subjected to chemical fertilizer application over longer periods of time. Thus, it is of importance to predict the N mineralization rates both for manure and for soil under natural conditions. Experimental results of this kind can provide full information on N dynamics in fields for policy decisions or regulations to reduce NO_3 leaching while maintaining crop yields. Likewise, we must consider other influencing factors such as soil types, climatic conditions, and cropping systems for this purpose.

Key words

Andisols, Fertilizer, Groundwater, Leaching, Manure, Methemoglobinemia, Nitrate, Nitrogen cycle

Introduction

The provision of a safe and stable supply of food and water is essential for mankind. The increase in the world population was supported by the improvement of agricultural practices, including fertilizer application, irrigation, and plant breeding. In fact, total production of cereals in the world has increased by a factor of 2.3 while the world population has increased by a factor of 1.9 since 1961 (Fig. 1). Particularly, chemical fertilizers have played a major role in the increase of cereal production (Brown, 1999) and their world consumption has increased as much as 7.4 times since 1961 (Fig. 1). Also, the large population in the world requires more water for agriculture, industry, and living conditions (Brown, 1999). Groundwater became more important as an alternative source of water supply for surface water, because the water quality of surface waters had been adversely affected by intensive human activities.

Under these circumstances, excessive application of nitrogenous fertilizers was reported to cause groundwater contamination by NO_3. Utilization efficiency of N fertilizers for outdoor cultivation of vegetables is usually 50% or less (Nishio, 2001; Vance, 2001). A large proportion of the unused N may leach out of the root zone and eventually to reach groundwater. In order to improve the N utilization efficiency and to minimize the risk of N leaching, farmers or policy-makers should select the most effective measures in the fields. However, the mechanisms of NO_3 leaching are not well understood and thereby the effects of improved practices can not be evaluated.

This paper aims to define the mechanisms of NO_3 contamination of groundwater associated with soil management in arable land. First, human concern and standard limits related to the NO_3 concentration in water were presented. Second, the current status of groundwater contamination was described in some countries. Also, the reason why fertilizer is applied at higher N rates than the amount that crops would take up throughout the growing period was given based on the N uptake patterns of crops. Then, N dynamics in soil and factors influencing NO_3 leaching were reviewed. Lastly, agricultural management practices to mitigate NO_3 contamination of groundwater were discussed.

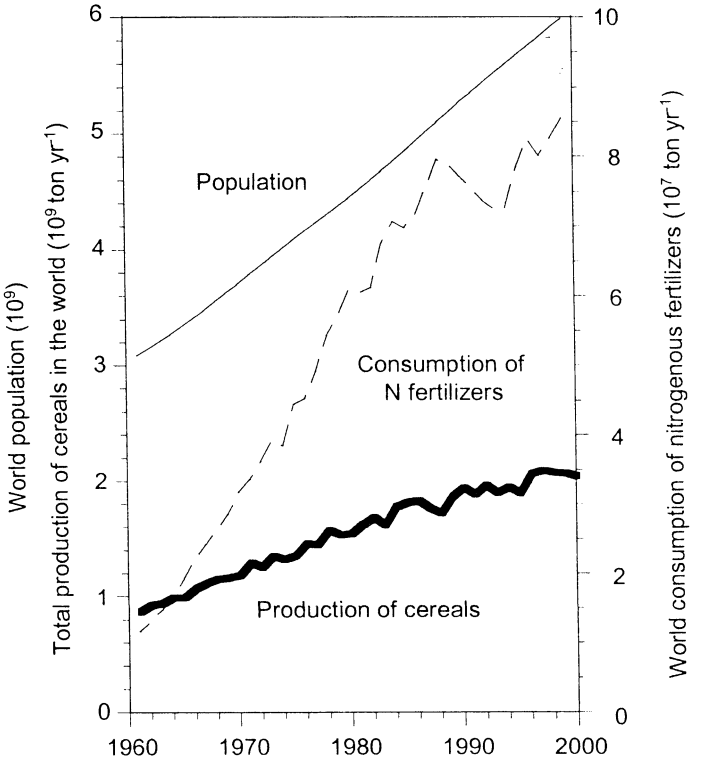


Fig. 1. Trends of population (thin line, left axis for scale), total production of cereals (thick line, left axis for scale), and consumption of nitrogenous fertilizers (broken line, right axis for scale) in the world since 1961. Illustrated from data by FAO (2001).

Health concern related to nitrate in groundwater

Nitrate contamination of groundwater has received considerable attention due to potential human health impacts from groundwater use for drinking water. Nitrate causes a problem when it is converted to nitrite (NO_2), while nitrate (NO_3) itself is not toxic. The toxicity of NO_2 is associated with methemoglobinemia, which occurs when NO_2 oxidizes hemoglobin to methemoglobin, resulting in a decrease in the oxygen-carrying capacity of blood (Addiscott et al., 1991; Canter, 1996). Infants under 3 mo of age are the most susceptible because their stomach is not acid enough to inhibit the microbes that convert NO_3 to NO_2 (Canter, 1996).

The World Health Organization (WHO) recommended guidelines for drinking water quality (NO_3: $\leq$50 mg NO_3 L^{-1}; NO_2: $\leq$0.2 mg NO_2 L^{-1}) in 1992, and the U.S. limit for NO_3-N in drinking water is 10 mg N L^{-1} (Canter, 1996), to offer the greatest protection to infants. The European Community (EC) directive (80/778/EEC) implements the WHO recommendation. In Japan, the water quality standard of NO_3-N for drinking water has been 10 mg N L^{-1} since 1958 and that of NO_2-N (0.05 mg N L^{-1}) was added into the items relating to

monitoring for drinking water in 1998. In addition, the Japanese Government established an environmental quality standard for NO_3-N in groundwater at 10 mg N L^{-1} to preserve water supply sources (Hayami, 1993) and enforced the Basic Law on Food, Agriculture, and Rural Areas to promote food self-sufficiency and sustainable agriculture in harmony with the surrounding environment in 1999.

Another aspect for environmental concern is the potential eutrophication in closed water bodies like lakes and closed seas (Koshino, 1976; Tabuchi and Takamura, 1985), where increased N levels promote the growth of algae, resulting in a decrease in the amount of dissolved oxygen. Eutrophication should be avoided due to the simplification of the ecosystems in the water bodies and the implication for drinking water supply affected by the growth of toxic algae.

Status of groundwater contamination by nitrate and fertilizer application

Western countries have turned their attention to NO_3 in groundwater since the 1960s because their major source of drinking water is groundwater (Ooe et al., 1999; Ogawa, 2000), as shown in Table 1 (Kobayashi, 1994). According to the U.S. Environmental Protection Agency (EPA), 1.2% of community water system wells and 2.4% of rural domestic wells were projected to contain more than 10 mg L^{-1} NO_3-N; approximately 4.5 million people drank nitrate-contaminated water (U.S. EPA, 1992). Also, in the European countries, drinking water sources are contaminated by NO_3, exceeding the WHO guidelines of 11.3 mg N L^{-1} (Kumazawa, 1999). In France, more than 1 million people drank water that contained more than 11.3 mg L^{-1} NO_3-N in 1981, with groundwater accounting for 91% (Fried, 1991). In the U.K., NO_3-N concentrations were found to exceed 11.3 mg L^{-1} in 192 wells for drinking water in 1990, and such polluted areas were designated as nitrate-sensitive areas (Ogawa, 2000).

Table 1. Contribution of groundwater to drinking water supply in selected countries.

	Year	Water supplied population (× 1000 persons)	Ratio of groundwater to drinking water supply (%)
Denmark	1986	3,084	100
France	1986	54,500	64
West Germany	1986	59,900	64
Netherlands	1986	14,590	59
Italy	1984	51,943	50
Finland	1986	39,710	49
U.S.A.	1986	219,000	30
U.K.	1986	56,000	28
Sweden	1986	7,242	25
Spain	1986	37,200	24
Japan	**1986**	**113,859**	**22**

After Kobayashi (1994).

In eastern and central England, NO_3 concentrations were increasing in groundwater, which provides 30-50% of drinking water (Spalding and Exner, 1993). Eight percent of the public waterworks in Denmark and 5% of those in former West Germany supplied groundwater containing more than 11.3 mg L^{-1} NO_3-N (Fried, 1991). In the Netherlands, the average concentration of NO_3-N in 56 shallow wells was 20 mg L^{-1} with the highest value being 81 mg L^{-1} (Ogawa, 2000). In Japan, a national groundwater survey conducted by the Environment Agency revealed that 9% in 1982 and 6.3% in 1998 of groundwater contained more than 10 mg L^{-1} NO_3-N (Environment Agency, Japan, 1993; 1999).

Agriculture was reported to be a primary source of NO_3 contamination in groundwater (Kawanishi et al., 1991; Hallberg and Keeney, 1993; Kumazawa, 1999; U.S. Geological Survey, 1999). The Royal Society in the U.K. estimated that the total amount of N leached from agricultural land was about 326,000 t in 1987 while N inputs from sewage and industrial effluent to freshwater and lakes were 150,000-160,000 t (House of Lords, 1989). In the Big Spring Basin of northeastern Iowa, which is fully used for agriculture, the NO_3-N concentration increased from 3 mg L^{-1} in the 1960s to nearly 10 mg L^{-1} in the early 1980s, while the amount of fertilizer N applied in the areas increased 2.5 to 3 times as a function of increasing rates of N application as well as the increase in the vegetated area (Hallberg, 1986). In Japan, NO_3-N concentrations exceeding 10 mg L^{-1} were detected in 15% of agricultural wells, but only in 0.05% of the wells in paddy fields (Kumazawa, 1999). Nagai (1991) reported that the NO_3-N concentration in groundwater continuously increased from less than 5 mg L^{-1} in

the early 1970s to 20 mg L^{-1} in the late 1980s under tea fields, where N fertilizer was intensively used, in Sizuoka. Hirata (1996) documented that the NO_3-N concentration in groundwater reached a maximum level of 90 mg L^{-1} under vegetable fields receiving N fertilizer at 500 kg N ha^{-1}. Ogawa (2000) showed that, below upland fields, the NO_3-N concentration in groundwater increased along with the direction of the groundwater flow.

Nitrogen is one of the most important plant nutrients. Needless to say, N fertilizer played an important role in the Green Revolution in the 1960s. National average nitrogenous fertilizer application rates, which were calculated from the data provided by the Food and Agriculture Organization (FAO, 2001), are listed in Table 2. Necessary N doses are different among countries owing to the difference in cover corps and climate conditions. Nitrogen application rates had increased in all the countries, especially in the developed countries from 1961 to 1979 (Table 2). Since the late 1970s, the N application rates have decreased in some developed countries (indicated as III), including Japan, because of the awareness of the excess application. On the other hand, the N application rates are still increasing in developing countries (indicated as I). The national average N application rate in Japan is not high in this list and is decreasing. Nevertheless, groundwater contamination by NO_3 has been reported, as mentioned above.

Nitrogen application rates widely ranged from 90 kg ha^{-1} for rice to 958 kg ha^{-1} for celery in Japan (Table 3; Nishio, 2001).

Table 2. National average N fertilizer applications to arable land in selected countries, in 1999, 1979, and 1961 (kg N ha^{-1}).

	Type[a]	Year		
		1961	1979	1999
World average	I	9	43	63
Ireland	I	18	218	399
Netherlands	III	245	619	375
Egypt	I	77	217	354
South Korea	I	107	215	265
Malaysia	I	32	138	255
U.K.	II	69	192	220
China	I	5	109	196
Viet Nam	I	3	16	195
Sri Lanka	I	61	90	186
Germany	III	72	185	170
France	II	32	123	140
Bangladesh	I	2	29	124
Norway	III	58	136	121
Chile	I	4	15	119
Denmark	III	48	149	110
Indonesia	I	5	34	109
Japan	**III**	**112**	**159**	**106**
Greece	III	30	122	105
Italy	III	27	117	101
New Zealand	I	2	9	100
Philippines	I	7	44	87
Spain	I	20	58	86
Finland	II	22	82	81
India	I	2	21	79
Thailand	I	1	9	73
Sweden	III	31	86	69
U.S.A.	II	17	55	64
Mexico	I	6	36	52
Canada	I	2	18	35
Brazil	I	3	21	31
Australia	I	1	6	23
Kenya	I	1	5	15

[a] I, Increased throughout the period 1961-1999; II, Increased from 1961 to 1979, then did not change;
III, Increased from 1961 to 1979, then decreased to 1999.

Excessive N in soil, which is shown as surplus N in Table 3, may cause large N gaseous and leaching losses from arable land, unless the patterns of N uptake by crops match N available in soil. Conversely, some excessive N is necessary as insurance when considering the N losses. Rainfall immediately after fertilization would bring a considerable amount of mineral-N in soil to deeper vadose zones, because crops at an early stage had not absorbed much N in soil by that time.

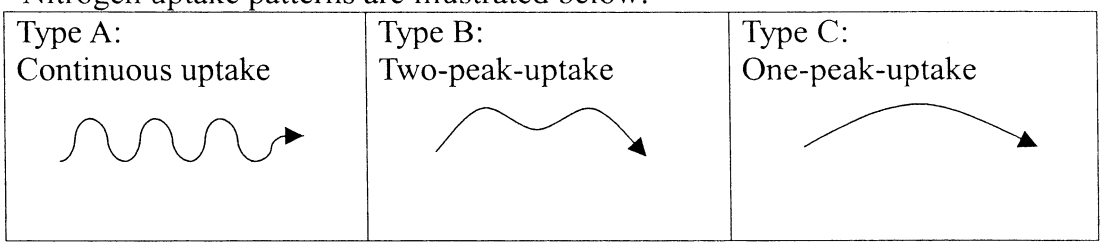
Nitrogen surplus increased with the N application rate (Table 3). Generally, crops need more N in soil at the stage of vegetative growth than at that of reproductive growth. Leaf vegetables such as celery and spinach are harvested at the stage of vegetative growth. Fruit vegetables such as tomato are continuously harvested at the stages of both vegetative and reproductive growth. Accordingly, leaf and fruit vegetables require a large amount of N in soil throughout the growing period, even at harvest (Type A), which induces more NO_3 leaching during the bare period after harvest. On the other hand, the crops of Types B and C do not need much N in soil at harvest because head-formating vegetables such as cabbage in Type B are harvested at the late stage of vegetative growth and other crops in Type C at the stage of reproductive growth (Souma, 1988). This is the reason for the larger N application rates for crops in Type A.

Adequate application of livestock manure to arable land is recommended for recycling valuable nutrient resources. In addition, some consumers have tended to prefer agricultural products grown with organic fertilizers in the last decade. The average application rate of manure (60 kg N ha^{-1}) is half as much as that of chemical fertilizer (113 kg N ha^{-1}) in Japan (Mishima et al., 1999). Although mineralized N from organic-N in manure must be considered as N input to arable land, evaluation of the mineralization rate of organic-N in manure is not easy (Addiscott, 1991).

Table 3. Nitrogen balance in fields for selected crops in Japan (modified after Nishio, 2001; Souma, 1988).

N uptake pattern[a]	Crop	Mineral N application (kg N ha^{-1})	N uptake (kg N ha^{-1})	N surplus (kg N ha^{-1})
Type A	Celery	958	226	732
	Egg plant	643	160	483
	Tea	628	278	350
	Tomato	321	101	220
	Spinach	220	63	157
Type B	Chinese cabbage	315	130	185
	Cabbage	338	217	121
Type C	Onion	248	93	155
	Water melon	161	72	89
	Potato	156	74	82
	Radish	133	94	39
	Rice	90	96	-6

[a] Nitrogen uptake patterns are illustrated below:



The nitrogen cycle in arable land

The N cycle is shown in Fig. 2. The main N inputs to arable land are the application of fertilizer and manure, and precipitation. The most common N fertilizer is urea (49% of total domestic demand in 1996; MAFF, 1998), followed by ammonium sulfate (20%), high-analysis compound fertilizer (13%), and ammonium phosphate (11%). Air-borne N inputs amount to about 10 kg N $ha^{-1}yr^{-1}$ (Tabuchi and Takamura, 1985; Hirata, 1996).

Nitrogen can exist in various forms in soil. In most of the soils, more than 90% of soil-N occurs in organic forms (Vinten and Smith, 1993). The decomposition of organic matter converts some organic-N to mineral-N (NH_4-N, NO_2-N, NO_3-N) through microbial processes (mineralization). At the same time, mineral-N can be converted to organic-N by microbial assimilation

(immobilization). Ammonium N is oxidized to NO_2-N and then NO_3-N by microorganisms (nitrification). Crops take up mineral-N from fertilizer or N mineralized from organic matter. Gaseous N losses occur due to denitrification under anaerobic conditions and ammonium volatilization under alkaline conditions. Furthermore, a considerable extent of N_2 fixation occurs in specialized groups of microorganisms for grain and pasture legumes.

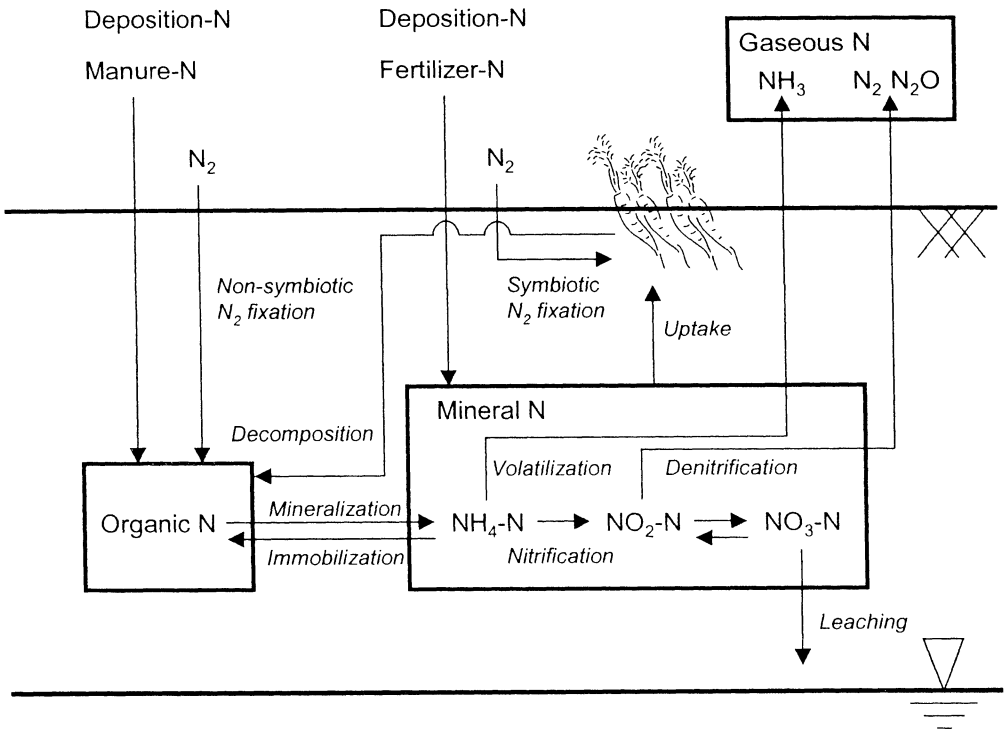


Fig. 2. Nitrogen cycle in soil.

Nitrate leaching and influencing factors

Nitrate leaching is the process whereby NO_3 in the soil solution is displaced from root zones by rainfall or irrigation water and eventually penetrates into groundwater (Fig. 2). General knowledge of the N cycling must be considered to select fertilization practices in a field. Nitrate N is freely leached below root zones, while NH_4-N is adsorbed onto the soil surface with negative charges. A number of agricultural practices and hydrogeological factors influence NO_3 leaching. The magnitude of the adverse impacts of these factors must be evaluated to improve agricultural management, resulting in the maintenance of crop yield while reducing NO_3 leaching.

We studied NO_3 leaching in a Japanese Andisol treated with three types of N fertilizers in addition to a control (SC: swine compost, CU: coated urea, AN:

ammonium N, or NF: no fertilizer) for 7 years (Maeda et al., 2003). Sweet corn (*Zea mays* L.) was grown in summer, followed by Chinese cabbage (*Brassica rapa* L. var. *amplexicaulis*) or cabbage (*Brassica oleracea* L. var. *capitata*) in autumn each year. In the chemical fertilizer plots treated with AN or CU, the NO_3-N concentration in soil water at 1-m depth increased markedly in the summer of the second year and fluctuated between 40–60 mg L^{-1} and 30–50 mg L^{-1}, respectively (Fig. 3). The difference in NO_3-N concentrations in soil water between the CU and AN plots probably resulted from differences in crop uptake of N from respective

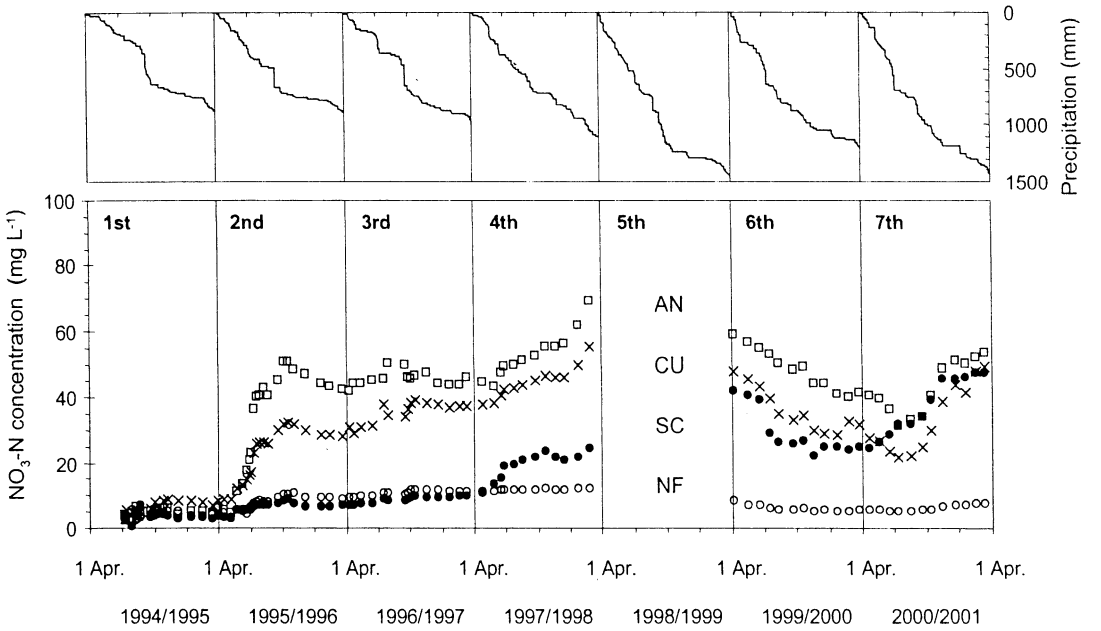


Fig. 3. Nitrate concentration of soil water at 1-m depth treated with different fertilizers. SC: swine compost, CU: coated urea fertilizer, AN: ammonium fertilizer, NF: no fertilizer. From Maeda et al. (2003).

sources. Matsumaru (1997b) also demonstrated that, based on a lysimeter study, slow-release fertilizer could markedly increase the yield of and N uptake by upland rice and taro in sandy soil, resulting in the suppression of N leaching, compared with conventional chemical fertilizer. In the SC plot, the NO_3-N concentration started increasing in the fourth year, reaching the same level as in the AN and CU plots in the late period of the experiment (Fig. 3). Increasing N mineralization owing to the lowered C/N ratio of the soil resulted in an increase in NO_3-N concentration at 1-m depth in the late period of the experiment. It is also likely to occur that the residual organic N from previously applied manure was mineralized, so that the total amount of mineralized N increased over the years (Angle et al., 1993; Thomsen et al., 1993; Bergstöm and Kirchmann, 1999). Repeated application of composts may simultaneously increase the risk

of serious NO_3 leaching, although the level of soil fertility may increase (Addiscott et al., 1991).

The following N and water balance equation on the soil surface (OECD, 1999) was used for predicting NO_3-N concentration in soil water at 1-m depth (Maeda et al., 2003):

$$PNC = \frac{PNP}{EW} \times 100 \quad [1]$$

where *PNC* (mg L^{-1}) is the potential nitrate concentration, *PNP* (kg ha^{-1} yr^{-1}) the potential nitrate present in soil, and *EW* (mm yr^{-1}) excess water (the difference between water input and evapotranspiration). *PNP* is obtained by subtracting the amount of N uptake, which refers to N in all parts of the crops removed from the plots, from that of N application in a year. The potential NO_3-N concentrations by Eq. [1] satisfactorily predicted NO_3-N concentrations in the AN and CU plots, but substantially overestimated that in the SC plot, presumably because a large portion of N from SC first accumulated in soil in the organic form (Table 4). Our results indicate that, under the Asian monsoon, excessive N from chemical fertilizers applied

Table 4. Potential NO_3-N present in soil (PNP), potential NO_3-N concentration (PNC) by the N and water balance equation, and 6-yr average NO_3-N concentration in soil water at 1-m depth.

Fertilizer treatment	*PNP*[a] (kg ha^{-1} yr^{-1})	*PNC*[b] (mg L^{-1})	6-yr average NO_3-N[c] (mg L^{-1})
SC	571	99	16
CU	192	33	28
AN	214	37	36
NF	−43	—	7

From Maeda et al. (2003).

[a] *PNP* was obtained by subtracting the amount of N uptake, which refers to N of all parts of the crops removed from the fields, from that of N application in a year. Data sets during the period 1994/1995-2000/2001 were used for the calculations.

[b] *PNC* was used as an estimate of NO_3-N concentration in soil water at 1-m depth. *EW* was estimated to be 576 mm yr^{-1}.

[c] Data sets during the period 1994/1995-2000/2001 except for 1998/1999 were used for the calculations.

to Andisols can cause substantial NO_3 leaching, while compost application is promising as a mean of establishing high yields and low N leaching during a few years, but would cause the same level of NO_3 leaching as in chemically fertilized plots over longer periods (Maeda et al., 2003).

Local conditions such as climate and soil type also affect NO_3 leaching. Nitrate concentrations of leachate increased with larger precipitation in Wisconsin (Andraski et al., 2000) and Denmark (Eriksen et al., 1999), whereas

they decreased in Minnesota (Randall et al., 1997). While watering treatment did not affect significantly NO_3-N leaching, soil types differing in texture and organic matter content affected it substantially (Bergström and Johansson, 1991).

Matsumaru (1997a) showed, using repacked lysimeters, that 25-32% of fertilizer-N leached out in volcanic ash soil, while 58-66% of that in sandy soil at the same application rates of fertilizer as in the volcanic ash soil. Andisols, volcanic ash soil, that covers more than half of the upland fields in Japan have high anion exchange capacity (AEC). High AEC values of soil are often significant for NO_3 adsorption (Katou et al., 2001). Preferential water flow in soil brings NO_3 to groundwater quickly (Maeda and Bergström, 2000). Preferential flow refers to macropore flow, fingering, and funneled flow (Steenhuis et al. 1995). Macropores, which reflect soil structure, root decay, wormholes, etc., constitute preferred flow pathways for infiltration of water in soil. Fingering occurs due to wetting front instability such as changes in hydraulic conductivity with depth and compression of air ahead of the wetting front. Funneled flow takes place when sloping geological layers cause pore water to flow laterally, accumulating in a low region. Many soil scientists have conducted studies on the complicated water flows in soil, but still their results are not easily adaptable to the prediction of NO_3 leaching.

Measures for the prevention of nitrate contamination

The attention of the present paper focused on measures for the prevention of NO_3 contamination from the viewpoint of the 'polluter pays' principle. In addition, the remediation of contaminated groundwater is difficult and costly, since contaminants from a non-point source like arable land tend to diffuse. Preventive measures for minimizing agriculturally based NO_3 contamination of groundwater are listed in Table 5. Measures for the treatment of NO_3 in groundwater were reviewed by Canter (1996).

Several technical measures can be used for reducing NO_3 leaching in arable land. The basic concept is associated with matching available N in root zones to meet crop N demand all the time. Slow-release fertilizers, mulches, effective application methods of fertilizer, and use of catch crops can improve N recovery rates by crops, resulting in high yields and low N leaching. Fertilization management influences the amount of available-N in
soil for crops. Substitution of slow-release fertilizers for readily available conventional fertilizers suppressed N leaching in short-term studies (Sakata et al., 1995; Matsumaru, 1997b). Mulching with a plastic film can lead to the increase of crop yields and reduction of N leaching by improving the water and biological conditions in soil (Islam et al., 1994). Split applications or banding of fertilizer reduced NO_3 leaching (Power et al., 2000). Nitrate leaching is also affected by manure types with different amounts of available-N (Beckwith et al., 1998). Coordination of crop need and fertilizer application

must be taken into account depending on the climate and soil conditions.

Table 5. Management measures for mitigation of NO_3 impacts on groundwater.

Technical measures: o Improvement of N recovery rates by new types of fertilizer / cropping systems / optimum coordination of crop need and fertilizer application; o Recycling of organic wastes; o Provision of land use barriers to N losses from agricultural watersheds.
Policy measures: o The Basic Law on Food, Agriculture and Rural Areas (enacted in 1999): proper use of fertilizers; improvement of soil fertility by effective use of livestock manure; o Designation of Nitrate-sensitive Areas.
Educational measures: o Farmer extension service; o Consumer awareness of the linkage between low-input products and the environment; o Community-supported agriculture.
Economic measures: o Taxation of N discharge / fertilizer; o Subsidies for sustainable agriculture; o Display for products grown under sustainable agriculture systems, enabling consumer choice.

Cropping systems, tillage, and other production practices can be considered as other influencing factors. Nitrate leaching was reduced by the introduction of catch crops such as perennial ryegrass and soybean (Aronsson and Torstensson, 1998; Power et al., 2000). The effects of tillage practices on NO_3 leaching were often site-specific (Power et al., 2000). Nitrate leaching was larger where crop irrigation was used (Burart and Kolpin,1992).

Inadequate treatments of organic wastes from livestock industries have resulted in N enrichment of water (Tabuchi, 2001). The organic resources should be used for nutrients in fields. However, excessive use of livestock manure as well as chemical fertilizer on arable land may cause groundwater contamination (Thomsen et al., 1993; Adams et al., 1994; Chang and Entz, 1996).

Wetlands and paddy fields can be barriers to N losses from agricultural land (Tabuchi, 2001). Nitrate concentrations in stream water that had penetrated from groundwater flowing below upland fields were reduced when the water flew through paddy fields (Abe et al., 1999), because the paddy fields have a large potential of N removal by uptake and denitrification (Maeda and Ozaki, 1994).

The other measures presented in Table 5 are potentially useful in controlling NO_3 contamination of groundwater associated with agricultural practices. These approaches can be used either singly or in various compatible combinations.

Conclusions

We must adopt proper measures to address water contamination by NO_3 immediately, because the amelioration of contaminated water resources would be impossible or is very costly. The author pointed out that balancing both effects of nitrogenous fertilizer, namely crop growth promotion and human health concern, should be considered at any levels and suggested that the mechanisms of NO_3 leaching must be understood to propose optimum balanced practices in a field.

Since many natural and practical factors affect NO_3 leaching and N dynamics are transient, we presently do not have any practical models to evaluate the long-range effect of improved soil management on NO_3 leaching precisely. We need develop mathematical models to propose the best soil management practices. In view of promoting sustainable agriculture, we should accumulate more knowledge on the fate of manure-N applied to fields. Moreover, preferential flow of water or solutes is another primary theme to improve the accuracy of N dynamics models.

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Biological Treatment Technology for Recycling Agricultural Waste for Sustainable Agriculture and Environmental Protection

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Abstract

Due to the increase in the intensive agricultural production system and operation, the practice of recycling agriculture waste in the sustainable agriculture and for the protection of environmental quality has changed. Because of this change, a review of the existing agricultural waste characteristics, the role of biological treatment technology, and the potential integration of treatment technology is made. Among the biological treatment technologies reviewed, only the composting process, biogas production and aerobic treatment of wastewater for sustainable agricultural production, and environmental quality are reviewed. Also, the integration of both anaerobic and aerobic treatment processes to achieve waste recycling and an example of the achievement of treatment technology and economics are both presented. Although other potential recycle alternatives, such as algae production, fish production, aquatic weeds and land application are not included in this review, they can be easily integrated into the three biological treatment technologies reviewed for the achievement of sustainable agriculture and environment quality protection for the intensive agricultural production system. Modification and integration are the two promising components of the biological treatment technology for the achievement of the goals planned.

Key words

Agricultural waste characteristics, biological treatment technology,

aerobic/anaerobic treatment, integration of anaerobic and aerobic, sustainable agriculture, environmental protection, biogas production, composting process, treated wastewater reuse, economic evaluation.

Introduction

Agricultural production is becoming more intensive with larger operations. The increased efficiency may generate various types of environmental problems, such as excessive nutrients and short oxygen levels in both the receiving soil and water body. General or common indicators, such as fish killing, odor generation, contamination of ground water and the decrease of crop production, occur because of improper management of agricultural waste/wastewater. These potential problems in environmental quality are closely associated with the wastes/residues from the agricultural production system. These wastes/residues can be in the form of animal wastes from animal production facilities, runoff and leachate from fertilized and manured fields, and liquid/solid wastes from food producing operations. Thus, the recycling agricultural wastes/wastewater has to consider and evaluate the consequence of the negative impacts of environmental quality. Generally, there are four possible methods for agricultural waste recycling, and are listed as follows (Polprasert, 1996; Loehr, 1984).

- Agricultural reuse
- Biogas production
- Aquacultural reuse
- Reuse of wastewater

The recycling method for agricultural wastes is mainly determined by the characteristics of various types of agricultural waste/wastewater. For example, animal waste/wastewater naturally pertains a high organic concentration and a low volume of flow, while food processing wastewater has high volume of flow and a lower organic concentration.

Characteristics of Agricultural Wastes

Although agricultural wastes have a very broad variety including food processing wastes, animal wastes, agricultural chemicals losses, crop residues etc., the potential agricultural wastes recycling in this review only focuses on the animal and food processing wastes. The characteristics of these wastes are important and should be understood. This will permit the type of treatment, recycling, and disposal to be properly selected. These wastes can be in the form of liquid or solid. Feasible treatment, recycling, and disposal methods will be varied with these characteristics as shown in Table 1. As indicated, the

biological treatment technology or method is suitably applied for both dissolved suspended and solid organic wastes. The parameter to be measured for the organic content includes BOD_5 (5 days Biochemical Oxygen Demand), COD (Chemical Oxygen Demand) and TVS (Total Volatile Solid) contents. The magnitude of these contents is COD > TVS > BOD_5. This reflects how much of the organic content remains in the agricultural wastes and can be further recycled for energy, animal feed and nutrient production via biological treatment methods. Examples for the characteristics of animal waste and food processing waste (tapioca starch waste) are presented in Tables 2 and 3, respectively. With the knowledge of the waste characteristics, it provides an opportunity for the reuse/recycle of bioenergy, animal feed, and soil conditioner production through the application of the biological treatment technology.

Role of Biological Treatment Technology for Agricultural Wastes Recycling

Understanding the biological treatment fundamentals is very important. Without understanding these fundamentals, the treatment processing will appear as a "black boxes". The objective of recycling agricultural wastes for maintaining sustainable agriculture and environmental protection will be hindered. In general, aerobic and / or anaerobic processes are the two primary biological treatment technologies which have been practiced. Aerobic process involves the reaction of the oxidation of organic matter in the wastes. In contrast, the anaerobic process is functioned by an anaerobic microorganism without the presence of oxygen. Thus, the main reaction products for the aerobic process are CO_2, H_2O and microbial biomass, while for the anaerobic process, the products are CH_4, CO_2, H_2O and microbial biomass. It must be emphasized that the cell yield (biomass produced per organics consumed) is lower in the anaerobic process, which has more advantages in sludge handling. These processes can be applied with various objectives of recycling, disposal and reuse. Common biological treatment processes are presented in Table 4. These biological treatment processes are mainly for dissolved and suspended organic wastewater. Applications of these technologies depend on the specific objective of agricultural waste recycling for sustainable agriculture and environmental quality protection. For recycling agricultural wastes, it is very important that production of composting product, biogas production and aerobic treatment for wastewater reuse should be reviewed and evaluated.

♦ For Composting Process:

It is an aerobic – biological treatment process, where the organic residues

or agricultural wastes are converted into humus by the numerous soil microbial biomass. As indicated by Polyprasert (1996), the objectives for applying composting process include waste stabilization, pathogen inactivation, nutrient and land reclamation, and waste product drying. The biochemical reactions can be divided into different stages of microbial growth with the change of temperature as shown in Figure 1. The composting process can be done in open windrows or enclosed with air supplying in a controlled unit shown in Figures 2 and 3, respectively. Composting can be completed in 5 – 7 days for the enclosed - air supplying controlled unit, whereas in open windrows, it may require for 3 – 8 days. In order to maintain proper microbial reactions in the composting process, the C/N ratio should be maintained about 20:1 to 30:1. For animal waste with some crop residues, they may provide an ideal C/N ratio to achieve an optimal stabilization process and conserve most of the nutrients. Benefits of recycling composted agricultural wastes to the soil include improved overall soil fertility and modify the soil pH. Also, if it is a long term application of composting product to the soil, soil erosion can be reduced, water retention capacity raised, soil structure improved, and subsequently, the crop production is improved.

◆ For Biogas Production Process:

In addition to composting technology, biogas production or anaerobic treatment technology is growing more popular and receiving more attention to animal producers. According to Christensen and Payseur (National Summit, 2003), approximately 250 million dry tons of animal manure is produced yearly in the United States. The National Pollution Discharge Elimination System (NPDES) and the Effluent Limitation Guidelines have been modified to include provision for confined animal feedlot operation (CAFOs), establishing technology - based effluent discharge standard for feedlot (beef, dairy, swine, and poultry subcategories). Also, regulation modifications are considered necessary because many agricultural sites are already saturated with nutrients (N and P), making it increasingly more necessary to reduce solid volume and to transport the manure off – site for use or disposal. According to Christensen and Payseur (National Submit, 2003), innovative technology and approaches are needed to make advances on the most different environment challenges in animal agriculture in the U.S. One technology that has demonstrated potential to assist in mitigating the impacts of animal manure on air and water resources, while producing other benefits such as energy and soil (fertilizer/conditioner), has been anaerobic digestion or anaerobic treatment, or biogas production. This technology has the potential to fit seamlessly for the agricultural production system, and to provide both economic and environmental benefits. Anaerobic

process is the natural process to stabilize the organic without the presence of oxygen. As reported by Polypraset (1996), the product of this process under normal operation conditions is presented as follows:

Methane (CH_4)	55 – 60%
Carbon dioxide (CO_2)	35 – 45%
Nitrogen (N_2)	0 – 3%
Hydrogen (H_2)	0 – 1%
Hydrogen sulfide (H_2S)	0 – 1%

Methane contains high calorific value ($\cong$ 9,000 kcal/m^3). The approximate heat value of the biogas is 4,500 – 6,300 kcal/m^3 depending on the content of CH_4. The anaerobic treatment process not only produces energy, it also provides waste stabilization (reduces the oxygen demand material or organic content), nutrient reclamation, pathogen inactivation and reduction of attraction of rodents and flies. Although there are some disadvantages, such as complicated operation and maintenance, and the market of biogas and digested sludge, which are still remained. The development of more advanced technology for the design and operation of anaerobic bioreactor may overcome these disadvantages. In general, two different types of anaerobic organisms, mesophilic and thermophilic, are functioned for the anaerobic treatment process as shown in Figure 4. It is necessary to maintain and operate under these two different temperatures which are considered optimal or suitable for the anaerobic treatment process. In addition to temperature, other operational factors, such as hydraulic and biomass retention times, nutrient requirement, inhibition prevention and mixing, all need to be maintained properly, as shown in Table 5. For the past decade, there are many anaerobic bioreactors being designed and operated as shown in Figure 5. Various types of bioreactors need to be designed and operated depending on the type of agricultural waste applied, temperature environment, reuse/recycle of the digested waste/wastewater, and biogas utilization.

♦ Aerobic Treatment for Wastewater Reuse:

This biological treatment process, generally, is integrated by following the anaerobic treatment unit process for further removal of oxygen demand materials. This will achieve more effectively for sustainable agriculture and environmental protection. Conventional activated sludge process as shown in Figure 6, can be applied to polish the anaerobic treated effluent for reuse in the agricultural production system. Although these processes can remove oxygen demand material very effectively, further removal of nitrogen and phosphorous are required to be integrated in order to improve the soil properties and increase crop production. Therefore, there are two types of biological treatment processes which allow the removal of nutrients and organic matter (oxygen demand

materials) at the same time because these processes include anoxic or anaerobic conditions in the aerobic treatment systems. These two processes are SBR (Sequential Batch Reactor) and continuous feed intermittently decanted (CEID) as shown in Table 6. Also, several activated sludge processes are modified to include anaerobic or anoxic zones in the systems for the removal of nitrogen and phosphorus as shown in Figure 7. Currently, Yang and his associates developed an EMMC (Entrapped Mixed Microbial Cell) Process as shown in Figure 8, for the combined removal of carbon and nitrogen simultaneously (Yang et al., 2002, 2003, 2004). This technology may hold a great potential for reuse/recycle of biologically treated wastewater because of its simple operation/maintenance for simultaneous removal of carbon and nitrogen contained in the wastewater. Pilot plant study using EMMC technology for both domestic sewage and agricultural wastewater is currently being initiated and developed. Also, a pilot plant study (Yang et al, 1997) using suspended culture on the combined anaerobic and aerobic treatment and reuse system was investigated for pig wastewater as shown in Figure 9. The result is presented in Table 7. This indicates that the integration of the biological treatment process (anaerobic and aerobic processes) is required to recycle and reuse of agricultural wastewater in order to maintain sustainable agriculture and protect environmental quality. Economic evaluation was conducted for this system. Two on-farm field studies for the swine waste treatment/reuse system including solid/liquid separation, anaerobic treatment and aerobic (complete and intermittent) treatment and polishing (or sedimentation) units have been investigated. About 20 – 25 sows operation was used to evaluate the overall process performance and economic evaluation. Based on the optimal operation process performance for these two systems, economic evaluation was conducted using the NPW (Net Present Worth) method. This value is related to the capital and annual operational and maintenance costs, with the annual interest rate of 6%, a life expectancy of 10 years. The land used for this evaluation was owned by the procedures. Farm size of 300, 1000, 2000, 3000 and 5000 size were evaluated for the NPW. It was assumed that the sludge and gas produced from the system could be reused and had value. Based on the break-even point analysis, the break-even point for integrating the complete aeration system is 830 pigs (average weight of 77 kg), and 166 heads for integrating intermittent aeration system as shown in Figures 10 and 11, respectively. It was also found that the utilization of biogas and digested sludge is essential for the benefit or profit of operating the integrating treatment system. Apparently, integrating the intermittent aeration unit in the swine waste treatment system provides reduction of energy consumption cost and reuse/disposal of treated wastewater without causing deterioration of environmental quality. It is, therefore, that the recycling of agriculture waste for

sustainable agriculture and environmental quality protection requires the inclusion of biological treatment technology.

Although the listed review on the biological treatment technologies are not totally included for the utilization of agricultural residues and protection of environmental quality, they are indeed the main streams of biological treatment technologies for the intensive agricultural production system. They can be modified to meet the goal or need, residue availability, the capability of operating individuals, and market and economic of products. As quoted by Loehr (1984), "The pressures for better resource conservation and pollution control are increasing, the need for better residue utilization exists, and many applicable technologies are available. The challenge is to change personal and public philosophies toward residue utilization and to provide the appropriate incentives to stimulate greater use of utilization technologies."

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Table 1. Feasible Treatment and Disposal Methods with Wastes of Different Characteristics

Wastes	Treatment and disposal methods
Liquid	
Dissolved organic wastes	Biological treatment, land treatment
Dissolved inorganic matter	Land disposal, physical or chemical treatment
Suspended organic wastes	Sedimentation, biological treatment, chemical precipitation, land treatment
Suspended inorganic matter	Sedimentation, land treatment, chemical treatment
Solid	
Organic wastes	Incineration, composting, land treatment, dehydration, animal feed
Inorganic wastes	Land disposal

Table 2. Bioengineering parameters of animal wasters (Taiganides, 1978)

Parameter	Symbol	Units	Pork pigs	Laying hens	Feedlot beef	Feedlot sheep	Dairy cattle
Wet waste	TWW	% TLW/day	5.1	6.6	4.6	3.6	9.4
Total solids	TS	% TWW	13.5	25.3	17.2	29.7	9.3
		% TLW/day	0.69	1.68	0.70	1.07	0.89
Volatile solids	TVS	% TS	82.4	72.8	82.8	84.7	80.3
		% TLW/day	0.57	1.22	0.65	0.91	0.72
Biochemical oxygen demand	BOD_5	% TS	31.8	21.4	16.2	8.8	20.4
		% TVS	38.6	29.4	19.6	10.4	25.4
		% TLW/day	0.22	0.36	0.13	0.09	0.18
COD/BOD_5 ratio	COD/BOD_5	Ratio	3.3	4.3	5.7	12.8	7.2
Total nitrogen	N	% TS	5.6	5.9	7.8	4.0	4.0
		% TLW/day	0.039	0.099	0.055	0.043	0.036
Phosphate	P_2O_5	% TS	2.5	4.6	1.2	1.4	1.1
		% TLW/day	0.017	0.077	0.008	0.015	0.010
Potash	K_2O	% TS	1.4	2.1	1.8	2.9	1.7
		% TLW/day	0.010	0.035	0.013	0.031	0.015

Table 3. Units mass emission rate (UMER) values of tapioca starch wasterwater in g/kg root (Thanh, 1984)

	Wastewater				
Characteristics	**A**	**B**	**C**	**D**	**Combined**
First-grade factory					
COD	**0.69**	**55.2**	**6**	**--**	**61.9**
BOD_5	**0.33**	**26.5**	**2.9**	**--**	**29.8**
Suspended solids	**0.54**	**10.5**	**3.7**	**--**	**15.7**
Dissolved solids	**4.91**	**46.3**	**9.6**	**--**	**60.8**
Second-grade factory					
BOD_5	**1.8**	**44.8**	**2.1**	**2.2**	**48.7**
Total solids	**3.1**	**102.8**	**2.2**	**2.2**	**109.2**
Suspended solids	**3.1**	**83.5**	**0.6**	**0.6**	**87.2**

Table 4. Common Biological Treatment Processes (Loehr, 1984)

Aerobic	Anaerobic
Activated sludge units	Anaerobic lagoons
Trickling filters	Digesters
Oxidation ponds	Anaerobic filters
Aerated lagoons	Photosynthetic
Oxidation ditch	Oxidation ponds
Suspended growth	Adherent growth (fixed film)
Activated sludge	Trickling filters
Aerated lagoons	Rotating biological contractors
Mixed digesters	Anaerobic filters
Oxidation ditch	Denitrification columns

Table 5. Process control parameters for anaerobic processes (Yang & Wang, 1990)

Parameter	Requirement	References
pH	6-8 (6.6-7.6 for methanogens)	Obayashi & Gorgan, 1985
Alkalinity	2500-5000 mg $CaCO_3$/L	Obayashi & Gorgan, 1985
pH_2	10-8 to 10-5 M	McCarty & Smith, 1986
Nutrient	C:N:P = 100:6:1	Jannet & Dennis, 1975
Trace nutrients	Fe, Co, Ni, & Sulfide	Speece, 1983
Toxicity	Toxicants: heavy metals, cyanide, ammonia, formaldehyde, pharmaceuticals, detergents, disinfectants, & solvents.	Speece, 1983
Temperature	30-40°C (50-70°C for thermophilic processes)	Henze & Harremos, 1983

Table 6. Comparison of SBR & CFID (Yang & Wang, 1990)

	SBR	CFID
No. of Tank	1	1
Feeding	**Batch**	**Continuous**
Operation Periods:		
Feeding	+	
React (Aeration)	+	+
Settle.	+	+
Decant	+	+
Idle	+	**Optional**

Table 7. Settled Effluent Quality of Combined Anaerobic Process (Two Stages without Sludge Recycling) and Aerobic System (Yang, 2001)

Parameter	Average value
Effluent Setting Time (minutes)	**4**
HRT for Anaerobic Process (days)	**32**
HRT for Algal-Biomass Receway System (days)	**3**
TCOD (mg/L)	**411**
$TBOD_5$ (mg/L)	**58**
SS (mg/L)	**50**
TKN (mg/L)	**64**
NH_3-N (mg/L)	**39**
NO_3-N (mg/L)	**20**
Total P (mg/L)	**33**
pH	**7.18**

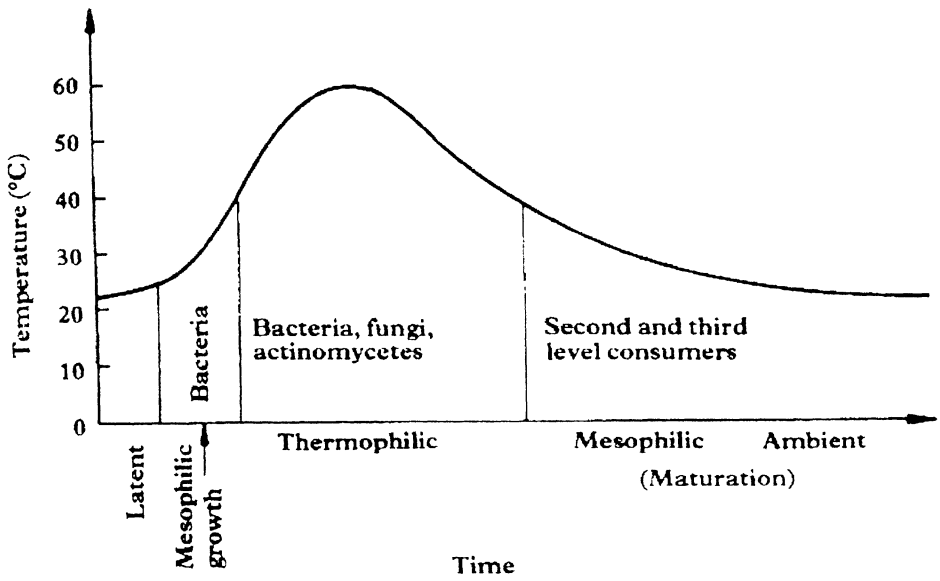

Figure 1. Patterns of temperature and microbial growth in compost piles (Polprasert, 1996)

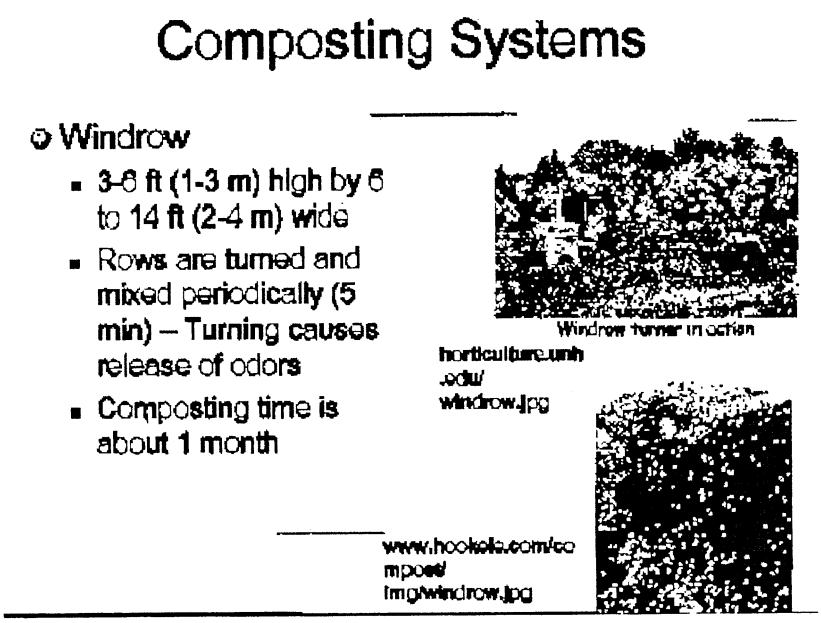
Composting Systems
Windrow
3-6 ft (1-3 m) high by 6 to 14 ft (2-4 m) wide
Rows are turned and mixed periodically (5 min) – Turning causes release of odors
Composting time is about 1 month
Windrow turner in action
horticulture.umh.edu/windrow.jpg
www.hookola.com/compost/img/windrow.jpg

Figure 2. Window Composting System (Adams, 2001)

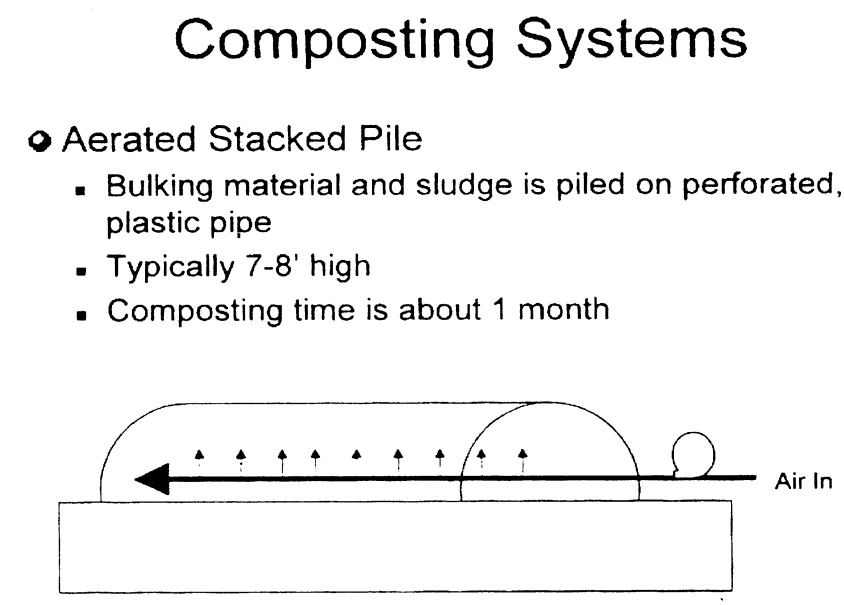
Composting Systems
Aerated Stacked Pile
Bulking material and sludge is piled on perforated, plastic pipe
Typically 7-8' high
Composting time is about 1 month
Air In

Figure 3. Aerated Composting Systems (Adams, 2001)

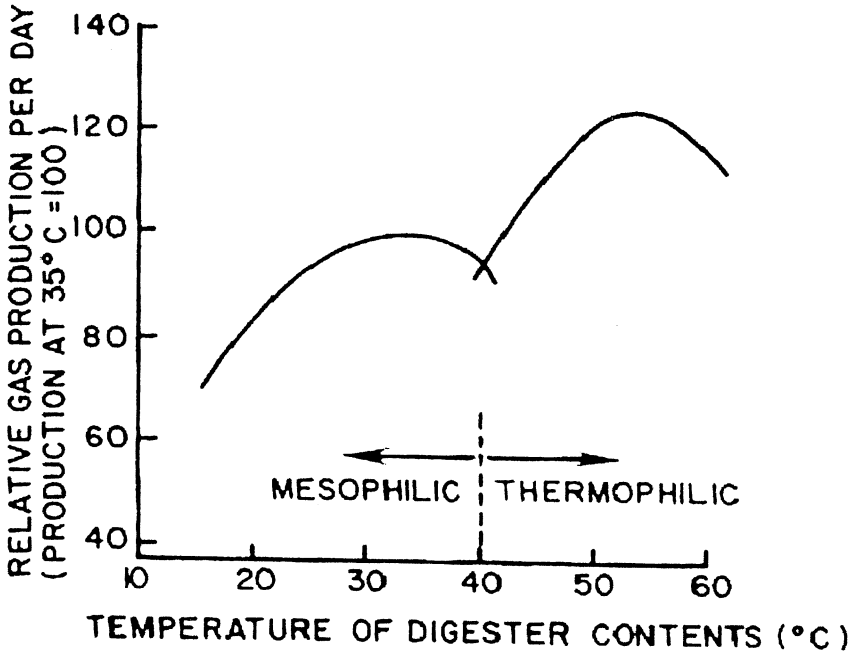

Figure 4. Temperature will affect activity of the microorganisms in anaerobic processes (Loehr, 1984)

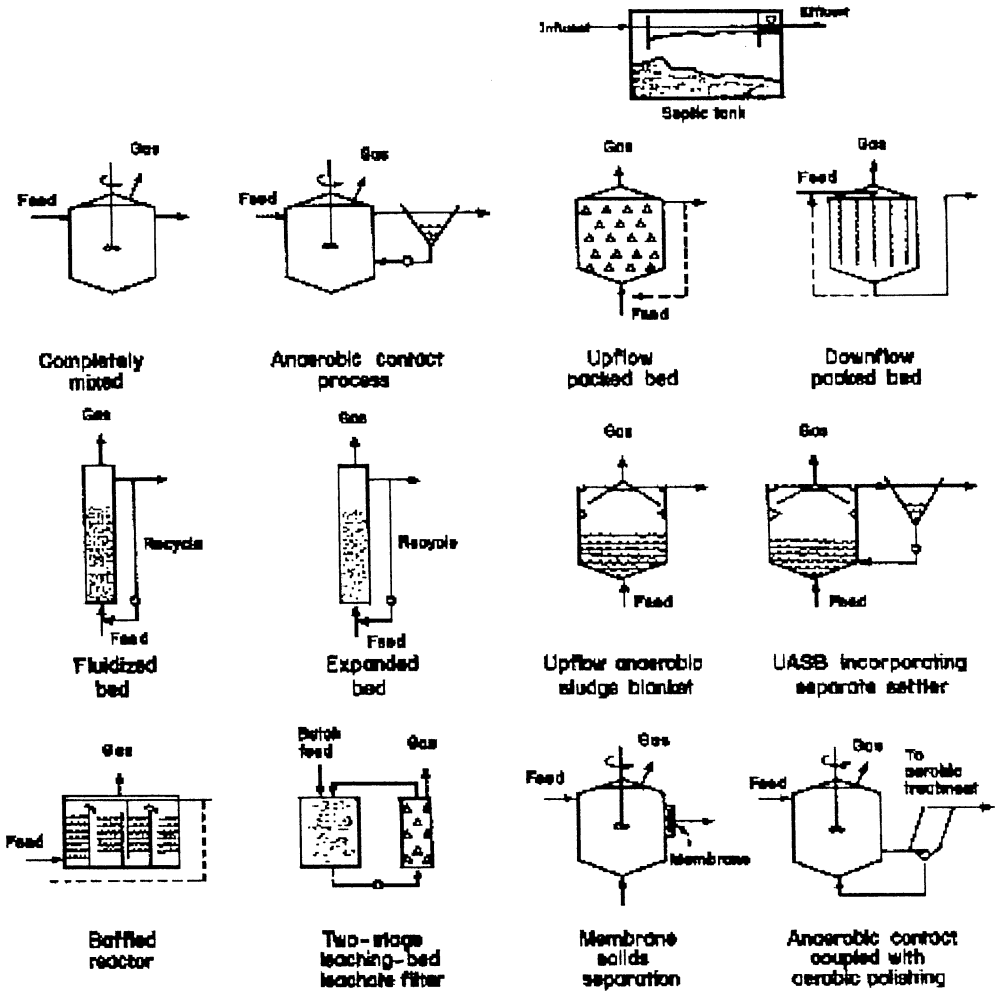

Figure 5. Reactor configurations for anaerobic biotechnology (Jewell, 1987 and Speece, 1983)

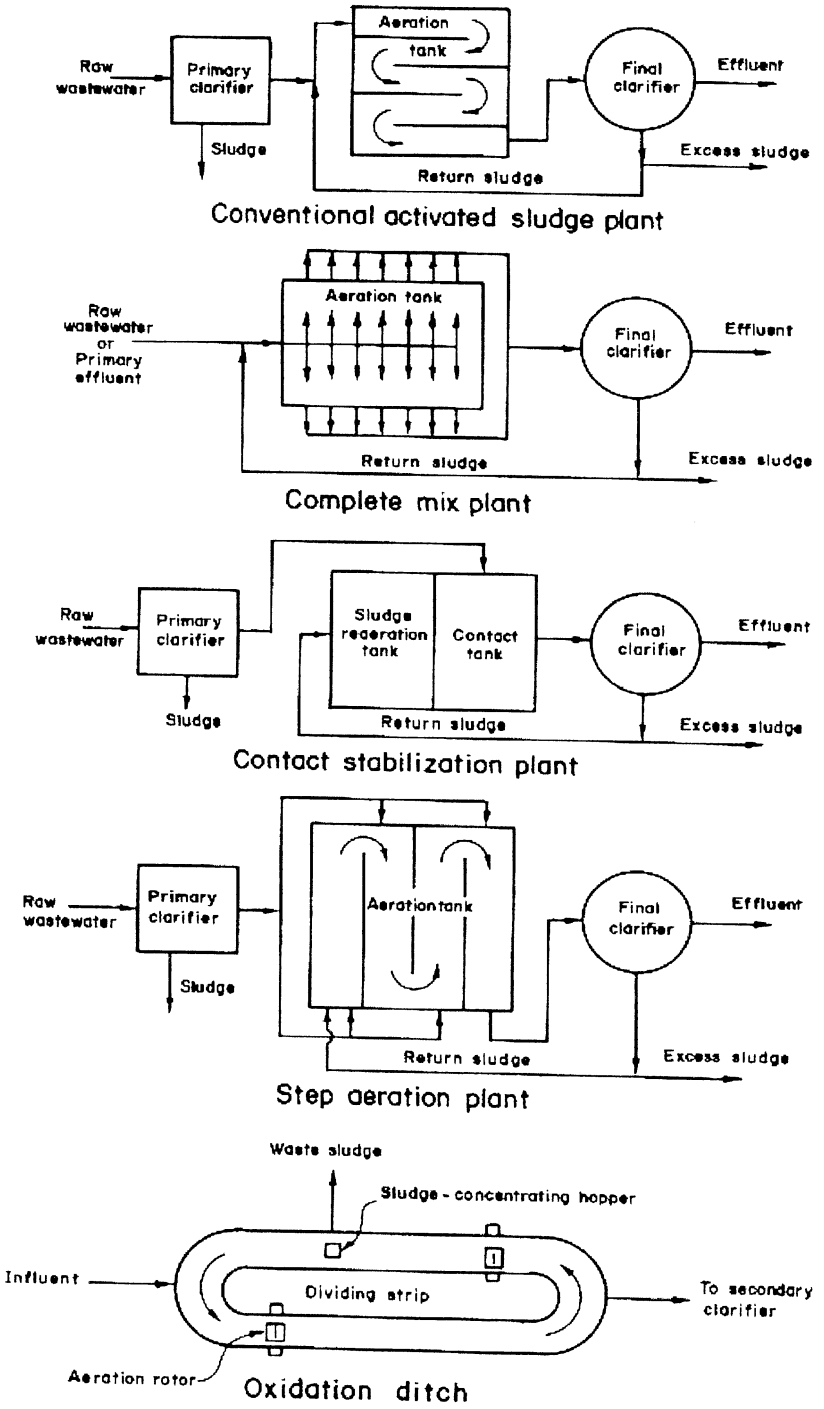

Figure 6. Modifications of activated sludge process (Cheremisinoff, 1987)

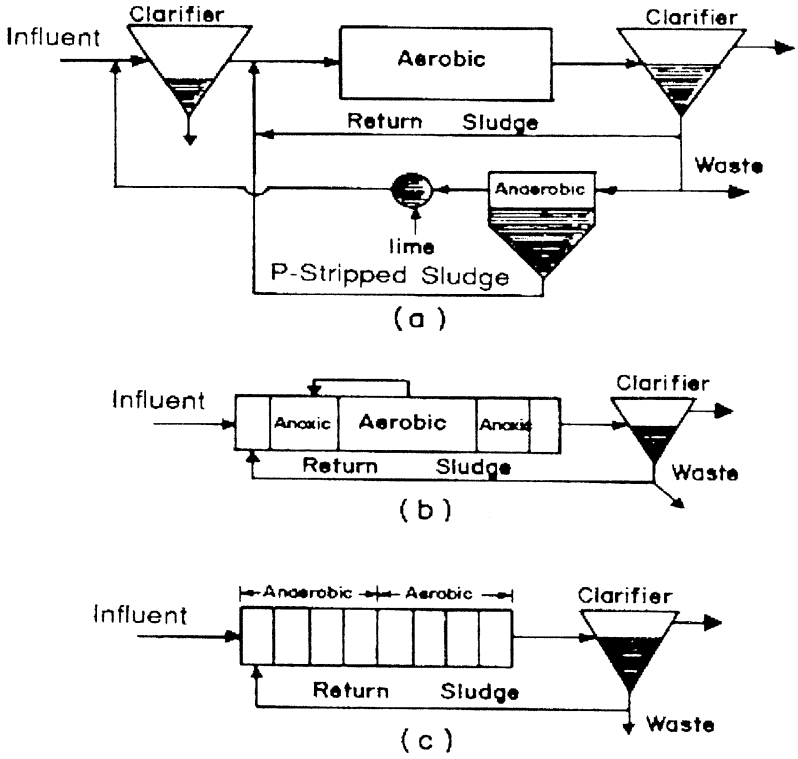

Figure 7. Various biological phosphate removal processes: (a) Phostrip process; (b) Badenpho process; (c) Air product process (Hao & Chang, 1988)

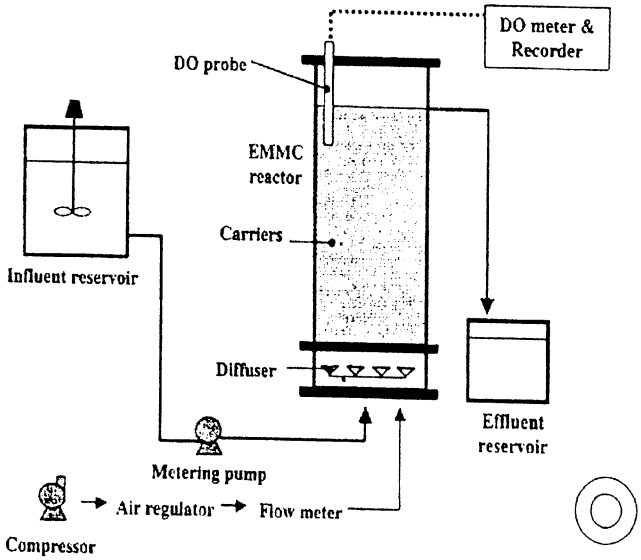

Figure 8. Schematic diagram of EMMC process (Yang, 2001)

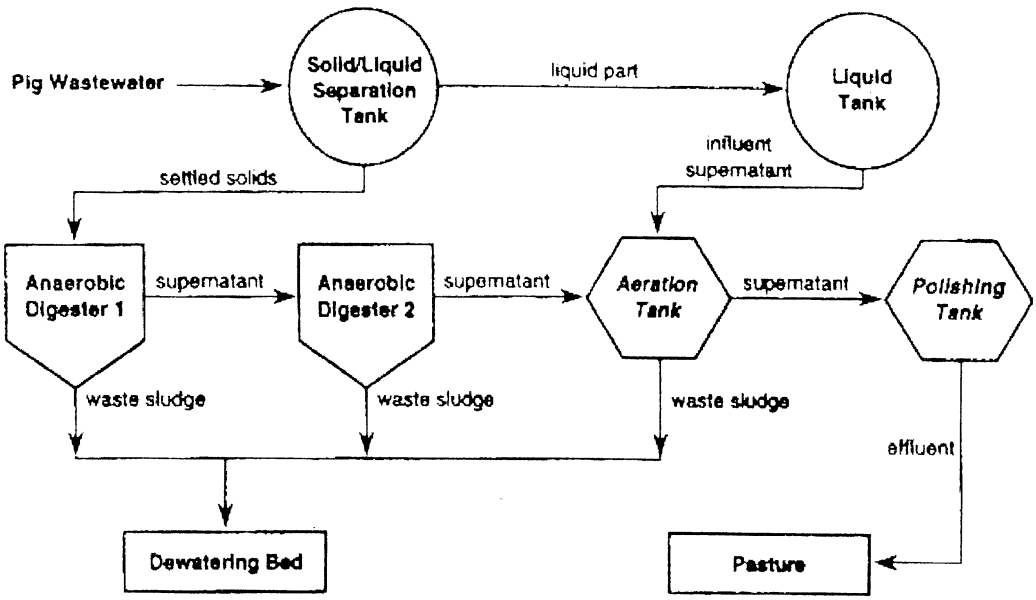

Figure 9. Schematic showing components of swine waste treatment system (Yang et al. 1997)

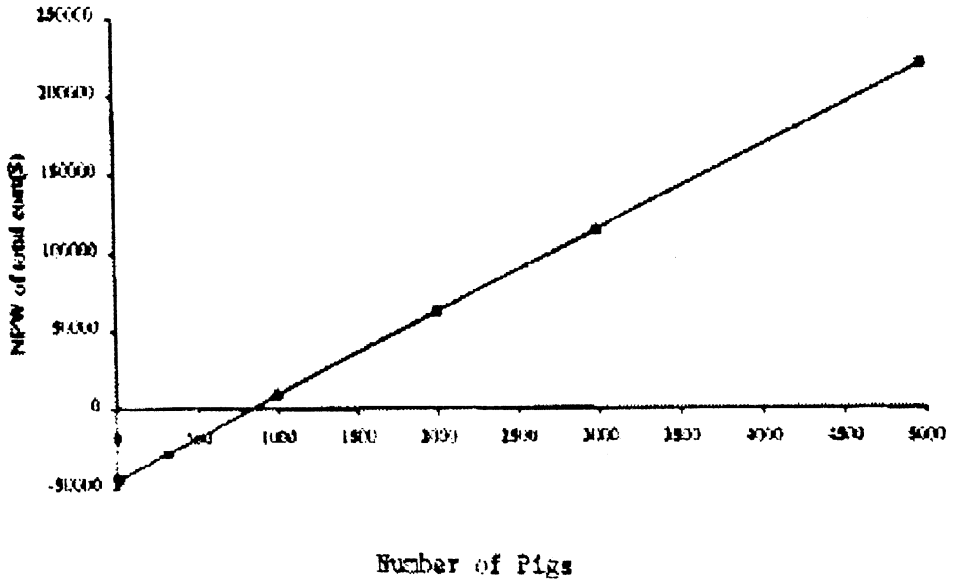

Figure 10. Relationship between pig numbers and present worth (NPW) of total cost. (Yang, 2001)

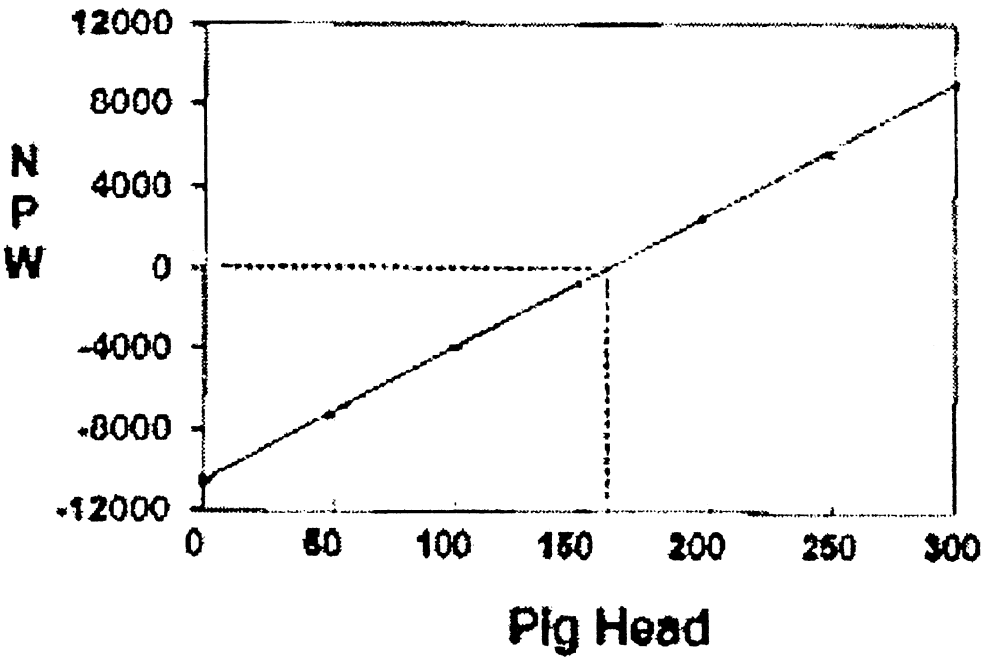

Figure 11. Determination of NPW breaken point with different sizes of operation (Yang, 2001)

The 3rd APEC Workshop on Sustainable Agricultural Development

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Pest Management

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Management of Plant Diseases without Using Pesticides in Sustainable Agriculture

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Abstract

In solving growers' new plant disease problems during the past three decades, various control methods without using any pesticide have been discovered. Through the systematic exclusion of each possible causal factor, and the confirmation of the working hypothesis by experimentation, several kinds of disorders were found to be due to nutrient deficiency and were controlled by application of appropriate nutrients. These include boron deficiency as the cause of latex secretion and deformity of papaya fruit, deficiency in calcium and boron as the cause of heart rot of banana tissue culture plantlets, and deficiency in nitrogen and phosphorous as the cause of ohia forest decline. The same approach was applied to discover hydrogen fluoride emitted from brick factories as the cause of marginal scorch of banana. The discovery forced the closing of several brick factories and the construction of new factories emitting insignificant amounts of hydrogen fluoride. Investigation of inhibition mechanism revealed that a soil suppressive to *Pythium splendens* was due to its high calcium content and high microbial population. Damping-off of cucumber was, therefore, controlled by mixing soil in planting holes with lime to increase calcium content and alfalfa meal to increase microbial population. Greenhouse tests confirmed the field observation that only young seedling roots are susceptible to *Phytophthora palmiuora*. The papaya replant problem caused by *P. palmiuora* was subsequently solved by replanting seeds in small quantities of pathogen-free virgin soil placed in the planting holes. All banana cultivars are susceptible to fusarium wilt caused by *Furarium oxysporum* f. sp. *cubense*. By screening tissue culture plantlets for resistance to the disease and selection for favorable traits from resistant clones, a resistant variety was released for commercial planting within 6 years. Among the extracts from various edible plants tested, sunflower oil was found to be very effective in controlling powdery mildews on several vegetable crops in the field.

From Pesticides to No Pesticides

The most commonly known method of controlling plant diseases in the field and in the greenhouse is through the use of synthetic chemical compounds.

The widespread use of such pesticides, however, has raised many concerns about the safty of foods, drinking water and farm workers, and their adverse effects on the environment. It is, therefore, imperative to find alternative control methods. In soluing new plant disease problems during the pest three decades, intentionally or not, we have discovered various control methods without using any pesticides.

Control Methods Resulted from Studying the Cause of Each Disease

Deformed-fruit disease of papaya

In the early 1970s, it was noticed in southern Taiwan that many papaya (*Carica papaya* L.) fruit were suffering from latex secretion and deformity. The disease, which is called "Ki-rui" locally, affects all commercial cultivars, and is most serious in sandy areas and during the dry winter. The percentage of unmarketable papaya fruit some times reached as high as 100% in some areas.

No insects were found to be associated with the deformed-fruit disease of papaya. Neither was a disease-spreading pattern observed in the fields. Its frequent occurrence in sandy soils and prevalence during the dry winter indicated that deficiency of nutrients might be a possible cause of the disease. Tissue analyses showed that the boron content in the leaf samples of diseased trees was much lower than that in the healthy trees. Tomato and lettuce grown in soils collected from the diseased field exhibited typical boron deficiency symptoms. These suggested that the deformed-fruit disease of papaya is caused by boron deficiency. This assumption was confirmed by the field tests which demonstrated that the application of borax or boric acid to diseased trees prevented the fruits from developing deformity (Wang and Ko,1975). Since then, the deformed-fruit disease has been under control by foliar or ground application of borax to papaya trees grown in sandy soils.

Heart rot of banana tissue culture plantlets

The propagation material of bananas (*Musa acuminata* Colla, genotype AAA) has been changed from conventional suckers to tissue culture plantlets by most growers in Taiwan in recent years (Ko et al, 1997). Yellowing and death of banana plantlets of unknown cause were observed from time to time before or after transplanting to the fields. Some growers suffered a 50 to 90% loss of banana plantlets in the fields in 1996. The symptoms consist of yellowing and necrosis of leaves, and degeneration of roots. The disease is commonly called heart rot because the affected seedlings also develop black cavity on apical meristem of the corm.

Insect larvae or eggs were not found in the corm during the early stage of cavity development. Plantlets planted in fresh soil which was mixed with pot soil containing plantlets with heart rot symptoms, in large pots did not develop the disease indicating that the disease is not infectious. When plantlets showing initial symptoms of heart rot were sprayed with calcium sulfate or sodium borate, new main roots and root hairs were produced, and the disease ceased to progress,

indicating that the disease is probably caused by mineral deficiency. The disease did not occur when plantlets were planted in soil amended with calcium and boron in small pots or in non-amended soil in large pots. Results show that heart rot of banana plantlets is caused by calcium and boron deficiencies, and that the problem can be solved by amending soil with calcium and boron or by using large size pots (Ko et al., 1997).

Ohia forest decline

Thousands of acres of native ohia [*Metrosideros collina* (Forst.) Gray subsp. *polymorpha* (Gaug.) Rock] forests on the island of Hawaii are declining. It is seen as a gradual thinning and unthrifty appearance of the crowns of trees followed by defoliation and death. The decline is of great concern because recent surveys have indicated an intensification of the deterioration of ohia forests. The ohia tree is important because it is a pioneer species on new lava flows and provides valuable watershed protection. Loss of ohia would mean the loss of forest cover.

The decline was not associated with the presence of any plant pathogens or with insect infestation. However, it was observed that ohia trees started showing the decline symptoms at a much younger age on massive lava than on small porous lava. This suggested the possibility of nutrient deficiency as the cause of ohia decline. To test this hypothesis, fertilizers were applied to the declining ohia trees. Declining trees treated with a complete fertilizer (NPK plus micronutrients) responded by producing numerous new leaf buds on branches and trunks. The trees also responded to a mixture of NPK without micronutrients. Application of N, P, and K individually or a mixture of micronutrients were not effective. Declining trees responded to a combination of NP, but not to combinations of NK and PK. Results indicated that ohia trees are declining because of deficiency in nitrogen and phosphorous.

Marginal scorch of banana

During the 1960s, a mysterious disease of banana called marginal scorch was noticed in several orchards in southern Taiwan. Water-soaked, irregular lesions started from the margins of affected leaves and, as the disease progressed, coalesced and turned dark green or dark brown, with waves of new lesions appearing behind the old ones. Fruit produced by affected plants were greatly reduced in size and not suitable for export. Because of the seriousness of the problem, the government allocated funds for plant pathologists in Taiwan to study this disease and also sought advice from foreign experts.

In the mid-1970s, I was invited to inspect the diseased orchards and develop methods to tackle the problem. Experiments performed under my supervision revealed the disease to be noninfectious. When diseased plants from the affected area were planted among healthy plants in a nonaffected area, the disease did not spread to healthy plants and, furthermore, diseased plants became healthy. In addition, the disease was found to be originated from the air and not from the soil. Healthy plants planted in soil transported from the affected area to a nonaffected area did not become diseased, but healthy plants

transported to the affected area all developed marginal scorch. The causal agent finally was found to be hydrogen fluoride emitted from nearby brick factories (Su et al., 1978 ; Sun, 1994). Analysis of leaf tissues showed that the concentration of fluoride was about 10 times higher in diseased leaves than in healthy leaves. Healthy leaves fumigated with hydrogen fluoride vapor developed symptoms of marginal scorch indistinguishable from those occurring in nature, and fluoride content increased more than sixfold in diseased tissues (Su et al., 1978).

After the revelation of the cause of marginal scorch, a lawsuit was brought by some banana growers, forcing the closing of several brick factories. When new factories were constructed to save energy and reduce labor costs the kiln design was changed from the conventional dome-shaped downdraft type to a modern tunnel type that utilizes residual heat for drying and preheating clay blocks. When hydrogen fluoride released from the clay blocks in the brick-forming chamber(>1,000 C) passed through the tunnel, about 98% was reabsorbed by the clay blocks drying in the tunnel. The kiln modifications, therefore, unintentionally solved the banana marginal scorch problem (Sun, 1994).

Control Method Discovered During the Study of the Inhibition Mechanism of Suppressive Soil

Damping-off of cucumber

Suppressive soils occurring naturally in fields are usually recognized by consistent observation of lower incidence of disease in a certain area in comparison with that in the nearby area. The suppressive fields involved are relatively large and the number of such suppressive soils which have been reported so far is very limited. Since both microorganisms and nonbiological components in soils are very diverse and their distribution is not uniform, it was considered possible that suppressive soil may exist as islands, small in area, in proportion to the total area of a conducive field.

A method was, therefore, developed for screening soils for suppression of sporangial germination. With this method soil from a small pasture in the South Kohala district on the island of Hawaii was found to be highly suppressive to germination of *Pythium splendens* and to the damping-off of cucumber caused by the pathogen (Ko and Ho, 1983). Suppression of *Py. spendens* in this soil was found to be due to a combination of high microbial population and high calcium content (Kao and Ko.1983; 1986a). Subsequently cucumber damping-off caused by *Py. spendens* was successfully controlled in the field by mixing soil in planting holes with alfalfa meal to increase the microbial population and lime to increase the concentration of available calcium (Kao and Ko, 1986b).

Idea oirginated from Field Observation

Papaya replant problem

Most of Hawaii's papaya is grown on approximately 3,000 acres of lava rock land in the southeastern corner of the island of Hawaii. In new plantings on virgin land initial infections of papaya by Phytophthora palmivora occur on fruit and the upper portion of the trunk during rainy periods. If the rainy season is prolonged, some growers may be forced to abandon their fields within 2 years after planting because of heavy infection. Nearly all papaya trees in the abandoned fields may be infected shortly by the fungus. Diseased fruit covered with sporangia and chlamydospores of P. palmivora fall to the ground and serve as an important source of inoculum in the soil. The fungus persists in the soil and causes root rot and death of seedlings when papaya seeds are subsequently planted in the same field. No resistant papaya cultivar has yet been developed. Because of the extremely rocky and porous nature of lava land, it is very difficult to control P. palmivora in replant fields with fungicides and fumigants.

It was observed in abandoned papaya fields that although roots of papaya seedlings were attacked by P. palmivora , roots of larger papaya trees remained free from infection by this pathogen, indication the possibility that only young seedling roots are susceptible. Greenhouse tests confirmed the field observation, and papaya replant problem was subsequently solved by replanting seeds in small quantities of pathogen-free virgin soil placed in the planting holes. Because of nutrient deprivation imposed by microbial competition, P. palmivora spores are not able to germinate and grow in soil. Virgin soil, therefore, remains free from the pathogen in infected fields (Ko, 1971; 1982). More than 30 years after its development, the virgin soil method is still being used for planting papaya in replant fields in Hawaii.

Screening for Resistance from Somaclonal Variants: a Fast Way of Obtaining Resistant Cultivars for Commercial Planting

Fusarium wilt of banana

Fusarium wilt of Cavendish bananas caused by race 4 of *Fusarium oxysporum* f. sp. *cubense* is the most serious problem in banana production in Taiwan. All the commercial banana cultivars tested are susceptible to this disease. Due to the existence of about 3% of mutants in the plantlets derived from 'Giant Cavendish' (Hwang, 1986), a screening program was initiated in 1984 to search for mutants resistant to the disease. During the period of 1984-1997, a total of 12 resistant clones were obtained, all derived from 'Giant Cavendish' (Hwang and Ko, 1988; 1989; 1991). Six clones are highly resistant and the other six moderately resistant. All are morphologically different from the parent and carry inferior horticultural traits such as taller stature, longer growth cycle, reduced bunch weight and poor postharvest characteristics. However, after repeated selection from the tissue culture plantlets derived from these resistant clones, clones with improved agronomical and physiological traits were obtained. The improved moderately resistant clone 'GCTCV-215-1' was

released as a new cultivar 'Tai Chiao No.1' for commercial planting in 1990, only six years after the initiation of the screening program. The fruit quality of 'Tai Chiao No.1' is comparable to that of 'Giant Cavendish'. Since 1991, more than one million 'Tai Chiao No.1' plantlets were planted each year. The wilt incidence on this variety ranged from 5.1 to 6.5%, compared to 42.6 to 69.0% on 'Giant Cavendish'.

Extracts from Edible Plants for Disease Control

Powdery mildew of tomato

We have formed a research group consisting of plant pathologists, entomologists, agronomists, horticulturists, and an oriental medical doctor to test extracts from edible plants including vegetables and medicinal plants for their ability to control plant diseases and insect pests. When tomato leaves were sprayed with 0.1% emulsified canola oil, corn oil, grape seed oil, peanut oil, safflower oil, soya bean oil or sunflower oil, the severity of powdery mildew caused by *Oidium neolycopersici* was greatly reduced. Among these edible oils tested, sunflower oil was the most effective in the control of powdery mildew. When sprayed with 0.5% sunflower oil, powdery mildew on tomato leaves was reduced to a negligible level. Scanning electron microscopy showed that control of powdery mildew with sunflower oil resulted mainly from the inhibition of conidial germination and suppression of mycelial growth of the pathogen (Ko et al., 2003). Emulsified sunflower oil has been used successfully in the control of powdery mildews on tomato, cucumber, pea, eggplant and bean in the field. Extracts from several medicinal plant species have also showed strong inhibitory effects on plant pathogenic fungi. Their ability to control diseases in the field is currently being evaluated.

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Sustainable management of insect-borne fungal plant diseases: A case study in Canada

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Abstract

Verticillium wilt of alfalfa, caused by *Verticillium albo-atrum,* is used as an example for discussion of insect transmission of fungal plant pathogens and management of insect-borne diseases. The disease is important in Europe, North America and northern Japan and it affects the tame hay production and other alfalfa-related industries, including the dehydrated alfalfa industry, the pedigreed seed and leafcutter bee industries and the livestock industry. Studies in Canada reveal that *V. albo-atrum* can be spread by insect, pests, predators and pollinators, as well as by alfalfa pollen. Some insects such as pea aphid, alfalfa weevil, grasshopper and leafcutter bee are effective vectors for the disease. Breeding for disease resistance is thus far the most effective means for control of verticillium wilt of alfalfa. Three alfalfa cultivars, Barrier, AC Blue J and AC Longview with high levels of resistance to verticillium wilt and bacterial wilt and adapted to the Canadian prairies, have been released from the breeding program at the Lethbridge Research Centre, Alberta, Canada. These disease resistant cultivars have increased forage yield, improved hay quality by reducing weed infestations, and prolonged stand life of alfalfa. Since verticillium wilt is an insect-borne disease, effective management of insect vectors should be part of the strategy for the control of this disease. Research on control of plant diseases by insect management remains a fertile ground and thus, demands the attention of plant pathologists, entomologists and plant breeders.

Key Words: alfalfa, *Medicago sativa,* Verticillium wilt, *Verticillium albo-atrum*, insect vector, disease resistance, control

Introduction

Some insects are of economic importance not only as chief pests but also as potential vectors for viral and fungal diseases of crops. The possibility of insects in mediating fungal diseases of plants has been reported in numerous reviews (Leach, 1935; Carter, 1973; Agrios, 1980; Steiner, 1984; Redfern, 1989; Webber and Gibbs, 1989; Wilding et al., 1989). However, insect transmission of Verticillium wilt of alfalfa (*Medicago sativa* L.) caused by *Verticillium albo-atrum* Reinke & Berthold, remained unknown until the discovery of pea aphids (*Acyrthosiphon pisum* (Harris)) as a vector for this disease (Huang et al., 1983).

Verticillium wilt of alfalfa is an important disease in Europe (Isaac, 1957; Krietlow, 1962; Raynal and Guy, 1977), North America (Atkinson, 1981; Arny and Grau, 1985) and northern Japan (Sato, 1994). Since the first report in Sweden in 1918 (Hedlund, 1923), the disease has become widespread in Europe (Krietlow, 1962; Raynal and Guy, 1977). Although Verticillium wilt was found in experimental plots of alfalfa at Normandin, Quebec, Canada in 1962 (Aube and Sackston, 1964), it did not become important in North America until the reported outbreaks in commercial fields in the Pacific Northwest States of the USA in 1976 (Graham et al., 1977; Christen and Peaden, 1981) and in the southern part of British Columbia, Canada in 1977 (Sheppard, 1979). In Asia, Verticillium wilt of alfalfa was first found in Hokkaido, Japan in 1981 (Sato, 1994). It was suggested that the disease was introduced to North America (Aube and Sackston, 1964) and Japan (Sato, 1994) through importation of infected alfalfa seeds.

The geographic distribution patterns in Europe, North America and Northern Japan suggest that Verticillium wilt of alfalfa occurs mainly in cooler regions (Peaden et al., 1985). However, the occurrence of this disease in southern California (Erwin and Khan, 1988; Gordon et al., 1989) confirms the suggestion by Heale (1985) that alfalfa strains of *V. albo-atrum* could spread into relatively warmer areas. Thus, it is possible that Verticillium wilt of alfalfa could occur in warm regions where alfalfa is grown.

Alfalfa is the most important and widely grown forage legume in Canada. The occurrence of Verticillium wilt of alfalfa in the provinces of British Columbia (Sheppard, 1979), Alberta (Howard et al., 1991), Saskatchewan (Gossen and Jesperson, 1988), Ontario (Busch and Christie, 1982), Quebec (Nicholls et al., 1987), Nova Scotia (Atkinson, 1981) and Prince Edward Island (Martin and Boswall, 1989) have posed a potential threat to alfalfa and its related industries in this country. The disease could affect tame hay production,

livestock production, the dehydrated alfalfa industry, and the pedigreed seed and leafcutter bee industries (Atkinson, 1981). In order to combat this disease, a research program on Verticillium wilt of alfalfa was initiated in 1981 at the Agriculture and Agri-Food Canada Research Centre, Lethbridge, Alberta, Canada. The program has led to the discovery of Verticillium wilt of alfalfa as an insect-borne disease. The objective of this review is to discuss the role of insects in the transmission of fungal plant pathogens and the strategy for management of insect-borne diseases, using Verticillium wilt of alfalfa as an example.

Insect Dissemination of Fungal Plant Pathogens

Alfalfa is a cross-pollinated, perennial crop that depends on insects for pollination and seed production (Goplen et al., 1980). The crop can harbor numerous species of insects including pests, predators and pollinators (Alberta Agriculture, 1985). Therefore, it is an ideal crop for studying insect-pathogen (*V. albo-atrum*) relationships. The relationships between insects and plant pathogens are often complex and relatively little is known concerning factors affecting these relationships.

Verticillium wilt of alfalfa is generally regarded as a systemic disease (Isaac, 1957; Christen and Peaden, 1981). However, the pathogen in diseased plants is mainly confined to vascular systems and distributes in a sporadic or discontinuous pattern (Pennypacker and Leath, 1983; Huang, 1989). While sporulation of *V. albo-atrum* does not occur on stems and leaves of newly infected plants, massive amount of spores are produced on the surface of dead tissues of old infected plants under humid conditions (Huang et al., 1983). This finding suggests the possibility of dissemination of spores of *V. albo-atrum* by insects under field conditions. A survey in southern Alberta in 1982 and 1983 revealed that numerous insect species collected from commercial fields of alfalfa naturally infested with *V. albo-atrum* were contaminated with the pathogen (Huang et al., 1983; Harper and Huang, 1984; Huang et al., 1986). They include alfalfa pests such as pea aphid (*Acyrthosiphon* pisum (Harris)), Adelphocorid plant bug beetle (*Adelphocoris lineolatus* (Goeze)), alfalfa weevil (*Hypera postica* Gyllenhal), Lygus plant bug (*Lygus* sp.), alfalfa curculio (*Sitona scissifrons* Say), alfalfa caterpillar (*Colias eurytheme* Boisduval), alfalfa looper (*Autographa californica* (Speyer)), spotted alfalfa aphid (*Therioaphis maculata* (Buckton)) and grasshopper (*Melanoplus sanguinipes* Fabricius and *Melanoplus bivittatus* Say); predatory insects such as lady bug beetle (*Coccinella* sp.), damsel bug (*Nabis alternatus* Parshley), minute pirate bug (*Orius tristicolor* (White)) and hover fly (*Eupeodes volucris* O.S.); and pollinating insects such as leafcutter bee (*Megachile rotundata* (Fabricius)) (Table 1).

Mode of Dissemination of *V. albo-atrum* by Insects

The acquisition and dissemination of fungal plant pathogens by insects depends upon the availability of inoculum and behavior of insects. For spores of *V. albo-atrum* produced on the surface of diseased stems, they can be carried on insect bodies by casual contacts. Spores of *V. albo-atrum* were most frequently trapped by pea aphids at the distal segments of legs, especially at the base of leg hairs (Huang et al., 1983). In leafcutter bees, spores of *V. albo-atrum* were frequently deposited at the base of spinelike or featherlike setae in alveoli of the cuticle or between the thorax and the first abdominal terga (Huang et al., 1986). Although spores of *V. albo-atrum* produced on old diseased alfalfa plants can be air-borne (Davies and Isaac, 1958; Lindermann et al., 1982; Howard, 1985), transportation of spores by insects such as pea aphids (Huang et al., 1983) and leafcutter bees (Huang et al., 1986) are more efficient than by air current as these insects are closely associated with alfalfa plants. Therefore, they target their delivery of the pathogen to alfalfa blossom or injured tissues for infection and development of the disease.

Some chewing insects are capable of transmitting *V. albo-atrum* by eating infected alfalfa tissues. For instance, *V. albo-atrum* survived passage through digestive tracts of grasshopper, alfalfa weevil and woolly bear caterpillar (*Apantesis blakei* Grote) (Huang and Harper, 1985). Another example is the pollinator, leafcutter bees, which can cut leaf pieces from *V. albo-atrum*-infected leaves and transport them to the hive for making brood cells (Huang and Richards, 1983; Huang et al., 1986). These findings suggest that when field conditions are not favorable for production of spores of *V. albo-atrum* from old diseased plants, the pathogen in newly infected plant tissues can still be effectively dispersed by chewing insects through ingestion of diseased tissues or transport of diseased alfalfa leaves.

Vector Capability of Insects

An ideal vector should be able to acquire the pathogen and transport it to the infection court for initiation of the disease on plants (Leach, 1935). Understanding the relationship between insects and plants is essential in determining the vector potential of each insect species. The capability of transmission of Verticillium wilt of alfalfa may vary among sucking, chewing and pollinating insects because of their differences in visiting and/or feeding habits on alfalfa plants.

Sucking Insects. Pea aphids are well known vectors for transmission of virus diseases of plants (Harris, 1980), yet they are rarely reported as vectors for

transmission of fungal diseases. Huang et al. (1983) first reported that pea aphids are important vectors of Verticillium wilt of alfalfa. Both wingless and winged aphids were capable of gathering spores of *V. albo-atrum* from diseased alfalfa plants and transporting them to young alfalfa tissues. The feeding wounds created by aphids are ideal locations for initiation of Verticillium wilt of alfalfa because they provided exogenous nutrients for germination of spores and subsequent infection and development of the disease on the plant. The studies suggest that pea aphids and perhaps other sucking insects may play a major role in the transmission of Verticillium wilt of alfalfa (Huang et al., 1983) and perhaps Verticillium wilt of other crops. Further investigations on vector potential of sucking insects on *V. albo-atrum* and other fungal pathogens in other crops are warranted.

Chewing Insects. Some leaf-chewing insects such as grasshopper and alfalfa weevil are important vectors of Verticillium wilt of alfalfa. Both adults and larvae of alfalfa weevil collected from a commercial field of alfalfa naturally infested with *V. albo-atrum* were contaminated with this pathogen (Table 1) (Harper and Huang, 1984). Release of the field-collected insects onto healthy alfalfa plants in cages resulted in transmission of the pathogen and development of Verticillium wilt on alfalfa plants (Harper and Huang, 1984). Several feeding trials revealed that *V. albo-atrum* in infected tissues survived after passage through the digestive tracts of leaf-chewing insects such as adult and nymph of grasshopper, adult and larva of alfalfa weevil and larva of woolly bear caterpillar (*Apantesis blakei* Grote) (Huang and Harper, 1985). Survival of *V. albo-atrum* in the gut system was of a non-persistent nature (Huang and Harper, 1985). Alfalfa seedlings inoculated with grasshopper feces infested with *V. albo-atrum* resulted in the development of Verticillium wilt within 4-6 weeks after inoculation (Huang and Harper, 1985). *Verticillium albo-atrum* in grasshopper feces survived for at least 2 years under dry and cold (-10 to -40^{B}C) conditions. Therefore, they could be an important source of inoculum for the disease in the field (Harper et al., 1988). These findings suggest that some stem- and leaf-chewing pests such as grasshoppers and alfalfa weevils are potential vectors for Verticillium wilt of alfalfa.

Pollinating Insects: Studies in the USA (Bohart, 1957) and Canada (Goplen et al., 1980) indicate that leafcutter bees of Eurasian origin are the most effective pollinator for alfalfa seed production because of their ability to trip the keel and the inclusive reproductive structures of alfalfa florets. Thus, leafcutter bees have made alfalfa seed production a highly specialized agricultural industry (Goplen et al., 1980). However, pollen grains of alfalfa are susceptible to infection by *V. albo-atrum* (Huang and Kokko, 1985) and the pathogen-infected pollen grains are often trapped by leafcutter bees foraging in diseased alfalfa

fields (Huang et al., 1986). These findings suggest that leafcutter bees can be potential vectors for Verticillium wilt of alfalfa because of their ability to carry *V. albo-atrum*-infected pollen grains (Huang et al., 1986), and transport them to alfalfa florets for causing infection of stigma, style and seeds during the process of flower tripping (Huang et al., 1985).

Management of Insect Vectors

Understanding vector behavior is crucial in developing strategies for management of insect-borne diseases. For the sucking insect, pea aphids, conidia of *V. albo-atrum* were transported to the probing wounds, which served as infection sites of the pathogen (Huang et al., 1983). For the chewing insect, grasshopper, Verticillium wilt can be transmitted via pathogen-contaminated feces (Huang and Harper, 1985). For pollinating insects such as alfalfa leafcutter bees, transmission of *V. albo-atrum* is mainly through the process of flower tripping which resulted in infection of stigma, style and seeds by the pathogen (Huang et al., 1985). The susceptibility of alfalfa pollen to infection by *V. albo-atrum* (Huang and Kokko, 1985) increases the danger of leafcutter bees by the transportation of *V. albo-atrum*-infected pollen grains to alfalfa flowers (Huang et al., 1986).

In Canada, there are several insecticides registered for control insect pests of alfalfa. For instance, Cygon (Cyanamid Canada Inc., Willowdale, Ontario) and Malathion (Cyanamid Canada Inc., Willowdale, Ontario) are registered for control of grasshopper, aphids, and alfalfa weevil (Alberta Agriculture, 1994). However, chemical pest management is environmentally unsound and it must be used judiciously. Other methods include the use of entomophagous fungus *Verticillium lecanii* (Zimmerman) Viegas for control of pea aphids (Harper and Huang, 1986) and grasshoppers (Johnson et al., 1988) but the research is still in its infancy. Control of insect pests may reduce damage to alfalfa and thereby reduce the associated risk of insect transmission of *V. albo-atrum*. However, there are no reports on control of Verticillium wilt of alfalfa by the management of insect vectors. This field of research deserves the attention of entomologists and plant pathologists. Since leafcutter bees are essential for production of alfalfa seeds, it is impractical to control leafcutter bees as a control strategy for Verticillium wilt of alfalfa. However, because leafcutter bees are reared and released to alfalfa fields for seed production, it is possible to minimize the transmission of *V. albo-atrum* and other blossom blight pathogens to alfalfa plants, using disease-free alfalfa fields for collection of bee cocoons for rearing the insects. Moreover, alfalfa pollen is susceptible to infection by mycoparasites, *Coniothyrium minitans* Campbell and *Gliocladium catenulatum* Gilmon & Abbott (Huang et al., 2003). The possibility of using leafcutter bees

to deliver pollen grains colonized by biocontrol agents for protection of alfalfa flowers from infection by *V. albo-atrum* and other blossom blight pathogens warrants further investigation.

Breeding Alfalfa for Resistance to Verticillium Wilt

Growing disease resistant cultivars is the most effective and economic method for control of Verticillium wilt of alfalfa. Since the first outbreak of Verticillium wilt in commercial fields of alfalfa in the USA in 1976 (Graham et al., 1977), breeding for resistance to this disease has become a primary objective in most of the alfalfa breeding programs in North America. Because bacterial wilt caused by *Clavibacter michiganense* subsp. *insidiosum* (McCull.) Davis et al., is another important disease of alfalfa in North America (Erwin, 1990), the breeding program at Lethbridge, Canada has focused on the development of new alfalfa cultivars with winter hardiness and high level of resistance to both Verticillium wilt and bacterial wilt (Hanna and Huang, 1984).

Some European cultivars of alfalfa such as 'Vertus' (Lundin and Johnsson, 1975), 'Maris Kabul' (Heale, 1985), and 'Lutece' (Gondran, 1978) are resistant to Verticillium wilt but are susceptible to bacterial wilt (Hanna and Huang, 1984; 1987). On the other hand, some North American cultivars of alfalfa such as 'Beaver', 'Pacer' (Huang et al., 1994), 'Anchor' (Huang and Hanna, 1991), 'Thor' and 'Vernal' (Gray et al., 1992) are susceptible to Verticillium wilt but are resistant to bacterial wilt (Hanna and Huang, 1987). By hybridizing European Verticillium wilt resistant cultivars with North American bacterial wilt resistant cultivars (Hanna and Huang, 1984), three new alfalfa cultivars, 'Barrier' (Hanna and Huang, 1987), 'AC Blue J' (Acharya et al., 1995) and 'AC Longview' (Acharya and Huang, 2000) have been released from the breeding program at the Lethbridge Research Centre, Canada. All three have high levels of resistance to both wilt diseases.

Field trials conducted in Alberta (Huang et al., 1994) and British Columbia, Canada (Stout et al., 1992) concluded that an alfalfa cultivar must be resistant to Verticillium wilt, bacterial wilt and winter hardy in order to maintain high yield and long life of stand. For example, a 7-year field trial (1987-1993) reveals that the annual dry forage yield for the cultivar 'Barrier' was 1904 kg/ha higher than the cultivar 'Pacer' and was 1830 kg/ha higher than the cultivar 'Vertus' (Huang et al., 1994). 'Barrier' is a hardy Canadian cultivar with resistance to both wilt diseases, and 'Pacer' is a hardy North American cultivar with resistance to bacterial wilt but susceptible to Verticillium wilt (Huang and Hanna, 1991; Huang et al., 1994). 'Vertus' is a Swedish cultivar with resistance to Verticillium wilt but susceptible to bacterial wilt and is not adapted to southern Alberta (Huang and Hanna, 1991; Huang et al., 1994) and southern British

Columbia (Stout et al., 1992). The potential benefits of growing disease resistant and well-adapted cultivars of alfalfa in western Canada were estimated at $26.6 million (in Canadian dollars) per year (Smith et al., 1995).

The success of a breeding program hinges on cooperative efforts of researchers in various disciplines. To date, most of the breeding efforts are confined to disease resistance and agronomy. In lieu of the importance of insects as pests or as vectors of plant pathogens, research on disease control strategies should be expanded to include methods for management of insects (pests and vectors) such as breeding alfalfa for resistance to vector insects. The field of pathogen, vector and host plant interactions remains a fertile area for research and thus, deserves attention of plant pathologists, entomologists, plant breeders, agronomists and molecular biologists.

Conclusion

Verticillium wilt of alfalfa, a serious disease in Europe, has become a major disease in North America since 1976 and in northern Japan since 1981. Numerous species of insects, pests, predators and pollinators can serve as dispersal agents for the pathogen. Some species such as pea aphids, alfalfa weevil, grasshoppers and leafcutter bees are proven to be effective vectors for transmission of Verticillium wilt of alfalfa. Breeding alfalfa for resistance to Verticillium wilt is the most effective and economic method for the management of this disease as the source of resistant materials is readily available in cultivated alfalfa and the method is environmentally sound. Alfalfa is a perennial plant and it is the habitat for numerous species of insects and microorganisms, including harmful and beneficial species. Since Verticillium wilt of alfalfa is an insect-borne disease, control of insect vectors may be of significance in reducing incidence and severity of the disease. However, knowledge about interactions of plant, plant pathogen and insect is vital for management of plant diseases and insect pests but research in these fields is largely ignored. For sustainable management of plant diseases such as Verticillium wilt of alfalfa and other insect-borne diseases, strong collaborative efforts are needed among plant pathologists, entomologists and plant breeders.

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Table 1. Contamination of *Verticillium albo-atrum* on insects collected from fields of alfalfa in southern Alberta during 1982-1983

Type of insect	Name of insect	Stage	Infested by *V. albo-atrum* (%)	Reference
Pest	Pea aphid (*Acyrthosiphon* pisum)	Adult, wingless	88[a]	Huang et al., 1983
		Adult, winged	73[a]	Huang et al., 1983
Pest	**Adelphocorid plant bug beetle (*Adelphocoris lineolatus*)**	**Adult**	**65[b]**	**Harper and Huang, 1984**
		Nymph	71[b]	Harper and Huang, 1984
Pest	**Alfalfa weevil (*Hypera postica*)**	**Adult**	**63[b]**	**Harper and Huang, 1984**
		Larva	**41[c]**	**Harper and Huang, 1984**
Pest	**Lygus plant bug (*Lygus* sp.)**	**Adult**	**63[b]**	**Harper and Huang, 1984**
		Nymph	**55[b]**	**Harper and Huang, 1984**
Pest	**Alfalfa curculio (*Sitona scissifrons*)**	**Adult**	**55[c]**	**Harper and Huang, 1984**
Pest	Alfalfa caterpillar (*Colias eurytheme*)	Larva	38[c]	Harper and Huang, 1984
Pest	Alfalfa looper (*Autographa californica*)	Larva	23[c]	Harper and Huang, 1984
Pest	Spotted alfalfa aphid (*Therioaphis maculata*)	Adult	75[b]	Harper and Huang, 1984
Pest	Grasshopper (*Melanoplus sanguinipes*)	Adult	11[d]	Harper and Huang, 1984
Predator	Lady bug beetle (*Coccinella* sp.)	Adult	13[b]	Harper and Huang, 1984
		Larva	20[b]	Harper and Huang, 1984
Predator	Golden eye lacewing (*Chrysopa oculata*)	Adult	76[c]	Harper and Huang, 1984
		Larva	37[b]	Harper and Huang, 1984
Predator	Damsel bug (*Nabis alternatus*)	Adult	70[b]	Harper and Huang, 1984
		Nymph	94[b]	Harper and Huang, 1984
Predator	Minute pirate bug (*Orius tristicolor*)	Adult	42[b]	Harper and Huang, 1984
		Nymph	22[b]	Harper and Huang, 1984
Predator	Hover fly (*Eupeodes volucris*)	Larva	67[e]	Harper and Huang, 1984
Pollinator	Leafcutter bee (*Megachile rotundata*)	Adult	30[f]	Harper et al., 1986

[a]Insects collected on August 31, 1982.
[b]Insects collected during August 25-27, 1982.
[c]Insects collected during July 6-13, 1983.
[d]Insects collected during June 20, 1983.
[e]Insects collected during August 20, 1982.
[f]Insects collected during mid-August, 1983.

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Safety Evaluation and Regulatory Control of Pesticide Residues in Chinese Taipei

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Abstract

Because agricultural production in Taiwan depends heavily on the use of pesticides, much attention has been focused on pesticide contamination of food and on the effects of pesticide residues on human health. The Taiwan Agricultural Chemicals and Toxic Substances Research Institute (TACTRI) conducts tests to evaluate the safe usage of pesticides used in Taiwan. In accordance with the Pesticide Control Act, minimum harvest intervals and tolerance levels for pesticides used on different crop groups are established before pesticides are approved for use in the field. The "tolerance" level of pesticides for different crop groups is determined on the basis of: i) the acceptable daily intake value of the pesticide; ii) the average daily consumption of each crop group by the Taiwanese people; and iii) the level of pesticide residues on different crops, estimated from supervised trials. Tolerance levels must be established before registrations can be approved.

Pesticide residues on vegetables and fruits are under heavy public scrutiny. Fifteen workstations for pesticide residue control have been set up by the TACTRI in different localities in Taiwan, and multi-residue methods are used for the analysis of these products. Pesticide residues commonly found on vegetables have now been identified. Educational programs for farmers have been devised, based on the analytical results obtained from these workstations. Risk assessments of dietary intakes of pesticides are carried out on a continuing basis. Results have shown that the dietary intake of pesticide residues by consumers is within safe limits.

Key words

Pesticide, Toxicity, Registration, Residue, Monitoring, Fruits and Vegetables, Risk assessment

Introduction

It is well known that weeds, plant diseases, and pre- and post-harvest pests are major factors causing reductions in potential crop yields. There are many ways to control diseases and insect pests, such as the application of pesticides, the breeding and cultivation of resistant crop varieties, biological control, etc (Li, 1999). Pesticides play an important role because they produce rapid and reliable results and are easy to use. Hence, the use of pesticides still remains as one of the most important control measures for plant protection. It is expected that this situation will continue in the future.

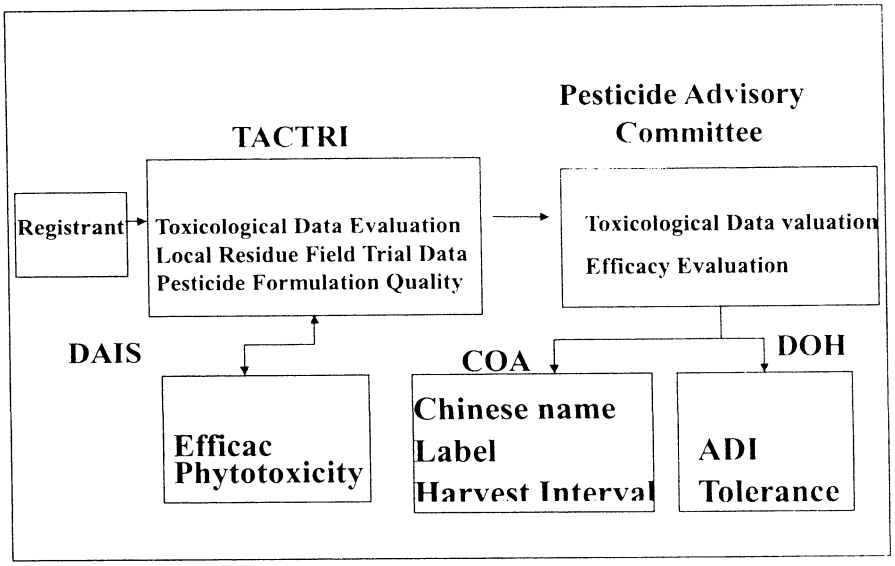
Although many methods, including integrated pest management (IPM), are being used in Taiwan for plant protection, Taiwan's agriculture is still heavily dependent on pesticide usage. Much attention has been focused on the regulatory control of pesticide residues to minimize contamination of food and any consequent effects on human health.

Agricultural Chemical Regulatory Laws

The Pesticide Control Act, promulgated and implemented in Taiwan by the Government in 1973, prohibits the sale, distribution and use of any pesticide without governmental approval. This approval is given only after the submission of necessary data on the formulated pesticide's effectiveness, the satisfactorily evaluation of its physical and chemical properties under local environmental conditions, and the establishment of a residue tolerance level. On average, about 80 applications for registration of pesticides are received annually. Applications might be for new compounds, for new formulations of registered compounds, or for registered products manufactured by a producer other than the original registrant. The data required for registration include: physical and chemical properties which will help with the evaluations of the qualities of the chemicals; toxicity to mammals to ensure the safety of a pesticide product and to protect farmers' health; avian toxicity; toxicity to aquatic organisms and to natural enemies of pests, to minimize the impact of pesticide usage on the environment; the distribution and degradation in water and soil, to reduce the potential for environmental pollution; residue and metabolism data on crops, to minimize field application rates and to protect the consumers from harmful agricultural products; efficacy and phytotoxicity, to ensure the effectiveness of pest control and to avoid damages to treated crops (Li *et al.*,). Field residue data and field efficacy data must be generated from local trials. Double-checking of the

specifications of the pesticide by governmental laboratories is also necessary.

TACTRI is responsible for residue analysis, specification analysis and evaluation of the required registration data on the pesticides to make appropriate recommendations for approval. The registration procedure is shown in Figure 1.



TACTRI = **Taiwan Agricultural Chemicals and Toxic Substances Research Institute**
DAIS = District Agricultural Improvement Station
COA = Council of Agriculture, Executive Yuan
DOH = Department of Health, Executive Yuan

Figure.1. Registration procedure in Taiwan

The following sections summarize the residue control programs related to food safety in Taiwan.

Establishment of Tolerance Levels for Pesticides on Different Crops

Before a pesticide is registered, supervised trials are conducted by TACTRI in cooperation with various agricultural research institutes and distinct stations. The pre- harvest intervals (PHI) are recommended by TACTRI by comparing residue data from supervised trials with the maximum tolerable residue limits established for a pesticide.

The requirements for setting tolerances involve both pesticide data and crop consumption data (Li *et al.*, 1981). The pesticide evaluation includes submission of data concerned with: product chemistry, acute and chronic toxicity, animal

and plant metabolism, field residues and processing studies. The chronic toxicity data and the field residue data are the most important information. The actual levels of residues found on each crop group resulting from the application of the pesticide at recommended rates are obtained from the field residue data. The acceptable daily intake (ADI) of the pesticides is derived from the chronic toxicity data. The established ADI values of pesticides registered in Taiwan are listed in a book published by TACTRI (Wong, 2000). The MPI (maximum permissible intake) of a pesticide by Taiwanese people is calculated from the ADI using an average body weight of 60 kg.

The average daily consumption of each type of crop per person is obtained from large-scale survey data. For the survey and calculation, crops were classified into 19 different groups (Table 1), based on the edible parts of the plants, expected distribution of residues and residue accumulation patterns. Some examples of the daily consumption data are shown in Tables 2 and 3.

Table 1. Crop grouping for tolerance establishment

Group	Crop
1. Rice	Rice
2. Wheat	Wheat, Barley
3. Maize	Corn, Sorghum
4. Brassica vegetables	Cabbage, Cauliflower, Head lettuce, Leaf mustard, Head cabbage, Big stem mustard
5. Leafy vegetables	Pak-Choi, Field mustard, Chinese Kale, Celery, Lettuce, Garlic green, Spinach, Water convolvulus, Chinese chive, non-heading type Chinese cabbage
6. Root and tuber vegetables	Potato, Radish, Carrot, Bamboo shoot, Water oat, Onion, Ginger, Taro.
7. Fruiting vegetables	Eggplant, Green pepper, Tomato, Tomato, Hot pepper, Day lily
8. Curcubit vegetables	Cucumber, luffa, Pumpkin, Wax gourd, Rag gourd, Chayote
9. Legume vegetables	Kidney bean, String bean, Pea, Asparagus bean, Garden bean
10. Melon	Water melon, Yellow melon, Netted Melon, Pineapple melon
11. Small Berries	Grape, Guava, Mulberry, Carambola, Wax-apple, Strawberries.
12. Stone fruits	Logan, Mango, Lychee, Loquat, Persimmon, Kiwi fruit [kiwi fruit do not have stones. Like persimmons, they are normally considered large berries]
13. Pome fruits	Apple, Pear, [Peach, Plum, Apricot, Cherry, Jujube
14. Citrus fruits	Orange, Tangerine, Grapefruit, Pomelo, Lemon.
15. Large berries	Banana, Pineapple, Papaya, Mangosteen, Sugar apple, Pitaya
16. Pulse	Red bean, Soybean, Mung bean, Peanut.
17. Mushroom	Mushroom, Straw mushroom, Jew's ear
18. Sugarcane	Sugarcane
19. Tea	Tea

Table 2. The daily consumption data of vegetable groups

Crops	Daily Consumption(kg)	% Intake
Leafy vegetable	0.083	8.56
Brassica vegetable	0.066	6.74
Fruiting vegetable	0.022	2.28
Cucurbits	0.029	2.97
Legume vegetable	0.012	1.17
Root & tuber vegetable	0.050	5.16

Table 3. Crop consumption data of fruit groups

Crops	Daily Consumption(kg)	% Intake
Large berry	0.028	2.83
Small berry	0.041	4.26
Stone fruit	0.012	1.19
Pome fruit	0.030	3.01
Melon	0.056	5.71
Citrus	0.066	6.82

The tolerance level for each group of crops is set in accordance with the maximum amount of residue that should be present at harvest time. However, the total number of crop groups for which a pesticide is registered is limited by the MPI value. In other words, the total actual amount of pesticide residue on a crop group for which a pesticide had been registered could never exceed the established MPI value. Table 4 shows the tolerances established for benomyl on different crops. The calculated intake is about 0.569 mg/person/day, which accounts for 47% of the MPI for benomyl. Thus, benomyl can be registered for use on some additional crops without exceeding the MPI. The sub-MPI, also known as the TMDI (mg/person/day) is equivalent to the tolerance times the daily consumption of crop groups. The SMPI is the sum of sub-MPI.

Tolerance levels for the pesticides registered in different crop groups have been proposed by the TACTRI (Wong, 1997). Up to February 2000, tolerance levels for 290 pesticides on different crop groups have been accepted by the Department of Health and have been listed in the Food Hygiene Law for food safety control (Anonymous, 2000)(Anonymous, 1995). So far, 1149 tolerances have been set for different crops. All the tolerances have been compiled in a book entitled "Guide to Pesticides on Crops in Taiwan"(Wong, 1997).

Table 4. The tolerances established for benomyl on in different crop groups
ADI = 0.1 mg/kg/day (WHO)
MPI = 1.2 mg/person/day

Crop Group	Tolerance (ppm)	Daily Consumption (kg/day)	TMDI* (mg/day)	Residue (ppm)	Actual intake (mg/day)
Rice	0.2	0.148	0.030	0.02	0.003
Root vegetables	0.2	0.050	0.010	0.02	0.001
Fruit vegetables	1.0	0.022	0.022	0.29	0.060
Small berry	2.0	0.041	0.083	0.20	0.008
Tea	5.0	0.002	0.009	0.50	0.001
Pome fruit	3.0	0.029	0.088	2.79	0.081
Melon	2.0	0.055	0.110	1.61	0.088
Citrus	3.0	0.066	0.198	2.78	0.183
Large berry	1.0	0.028	0.028	0.01	0.003
SMPI			0.569		0.428

*TMDI: Theoretical maximum daily Intake

Residue Analysis of Field Samples for Farmer Education

In order to enforce tolerances at the farmer's level, an inspection-education program has been set up by the extension agency and TACTRI (Fig.2). Fifteen working stations of TACTRI, in different locations in Taiwan, are responsible for the analysis of pesticide residues on vegetables and fruits, and also for farmer education based on the residue results obtained. From pesticide usage survey data, 77 commonly used pesticides are sought in each vegetable sample, and 24 to 42 pesticides are sought in each fruit sample, depending upon the type of fruit (Fig. 3). If results of these long-term and country-wide surveys indicate that a pesticide residue exceeded the tolerance level, then a follow-up investigation would be undertaken to uncover the possible causes, such as the usage of cultural methods and the technique of pesticide application. The development of the effectiveness of each pesticide against pests is also assessed. Farmer education follows after the problems have been solved. Approximately 15,000 samples are analyzed annually. Since the establishment of the inspection-education program, the number of vegetable samples, which have violated tolerances, has been greatly reduced (Fig.4). It has fallen from 15.4 % in 1979 to 1.8% in 1999. The summarized results of residue analysis during the fiscal year 1999 are given in Table 5(Residue Control Department, 1999).

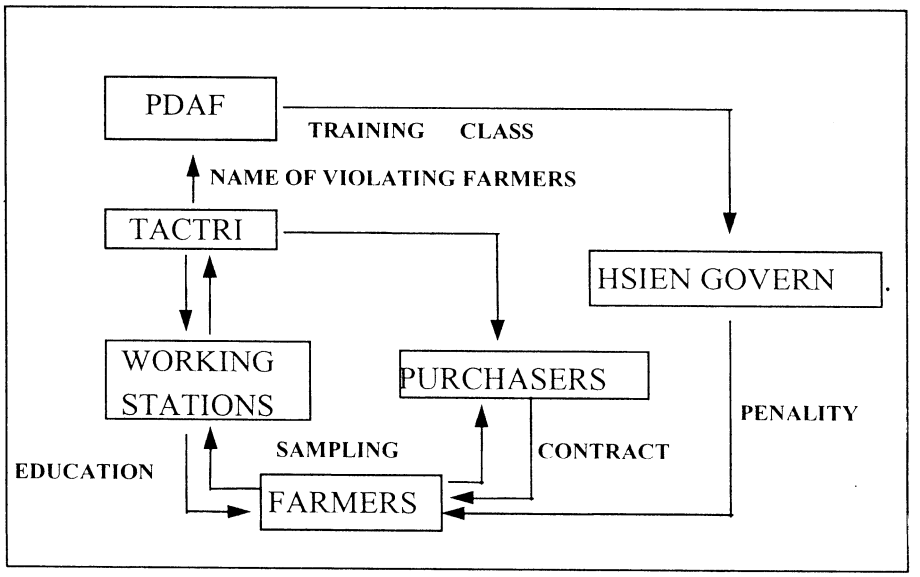


Figure 2. Working systems used to prevent pesticide residue problems on vegetables and fruits

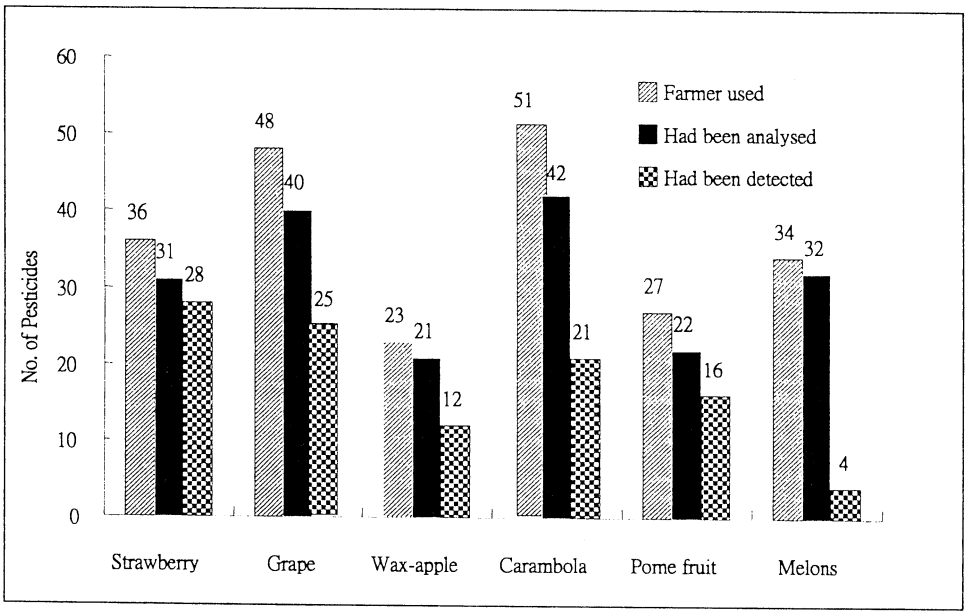


Figure 3. Survey of pesticides used on fruits

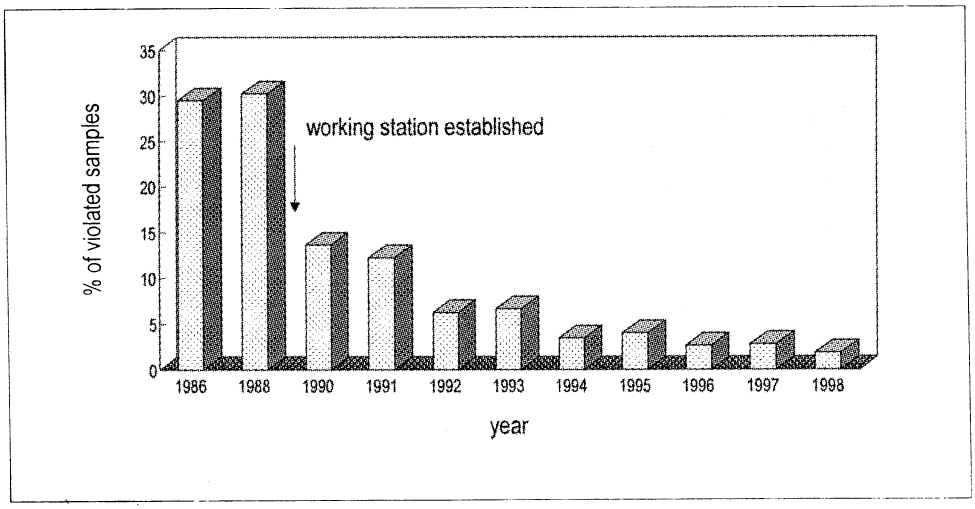


Figure 4. The percentage of samples exceeding tolerance levels before and after the establishment of working stations

Table 5. Summarized Results of Residue Analysis during the Fiscal Year 1999

Crops	Samples analyzed	Samples exceeding	Percentage (%)
Leafy vegetables	5058	150	3.0
Brassica vegetables	379	5	1.3
Fruiting vegetables	798	14	1.3
Cucurbits	1013	8	1.7
Legume vegetables	224	12	5.3
Root and tuber vegetables	956	1	0.1
Large berries	638	3	4.7
Small berries	1532	8	0.5
Stone fruit	825	19	2.3
Pome fruit	788	9	1.1
Melons	134	2	1.5
Citrus	1025	9	0.8
TOTAL	13,370	236	1.8

Risk Assessment of Dietary Exposure to Pesticides

Public concern over pesticide residues on vegetables and fruits has been increasing in recent years. The risk to human health is due to pesticide residues in the edible parts of the crop and the consequent daily intake of these residues.

Market basket surveys of pesticide residues in rice, vegetable, and fruit samples were carried out during 1992 to 1993. A total of 962 samples including 90 rice, 644 vegetables and 228 fruit samples were collected from markets at 11

different localities in Taiwan. Samples were analyzed using a multi-residue method (MRM). This method was used to search for 77 different pesticide residues. A total of 31 pesticides were found in various samples. Twelve pesticides were found in more than 1% of samples. Follow-up work calculated the toxicological risk by comparing the actual residue contribution (ARC) with the acceptable daily intake (ADI) for the same 12 pesticides (Wu, 1992). The results of this study are shown in Table 7. The actual residue contributions (ARC) were calculated using the following equation:

$ARC = \Sigma (Fi \times Ri)/BW$

Fi = the daily consumption of the crop group (kg/person/day)

Ri = the residue level of the pesticide found on the crop group (ppm = mg/kg)

BW = the average body weight of Taiwanese (60kg)

The risk assessment results are shown in Table 6. The results indicated that the ARC of the 12 pesticides consumed accounted for only 0.54 to 30.00 % of their acceptable daily intakes (Wu, 1992).

Table 6. Risk assessment of dietary exposure of pesticides

Pesticide	ADI(mg/kg/day)	ARC(mg/kg/day)	%ADI
EBDCs	0.05	0.00568	11.35
Chlorothalonil	0.03	0.00044	1.47
Methamidophos	0.004	0.00035	8.75
Acephate	0.03	0.00044	1.47
Monocrotophos	0.0006	0.00018	30.00
Chlorpyrifos	0.01	0.00023	2.32
Permethrin	0.05	0.00098	1.96
Cypermethrin	0.05	0.00030	0.60
Carbofuran	0.01	0.00036	3.60
Ethion	0.002	0.00031	15.50
Formetanate	0.037	0.00020	0.54
Carbendazim	0.05	0.00031	3.10

Similar studies were carried out during the year 1999 to 2000 (Tsai, 1999a)(Tsai, 1999b). A total of 3262 samples, including 1064 rice, 1178 vegetables and 1202 fruit samples were collected from markets at different areas in Taiwan. Samples were analyzed using an improved multi-residue method. This improved method could be used to detect 113 pesticides on vegetables and

125 pesticides on fruits. A total of 65 different pesticides were detected on the vegetable samples, 44 on fruit and 29 on rice. Most of the pesticides detected were also commonly found on vegetables, fruits, and rice. The total number of pesticides detected was 69. After calculating the ARC of these 69 different pesticides, it was found that the ARCs of 16 pesticides were between 1.15% of ADI to 22.63% of ADI, 18 pesticides were between 0.12% to 0.97%, 24 pesticides were between 0.02% to 0.09%, and 10 pesticides were below 0.01% of ADI. Apparently, the risk posed by these pesticide residues to the consumers' health is very low. However, the ARC of EPN found in this study was about 124% of the ADI. This is because the ADI had been lowered to 0.00001 mg/kg/day. Further action will be taken on this finding. Table 7 gives a list of pesticides where the ARC value exceeded 1.15% of the ADI value.

Table 7. Risk assessment of dietary exposure of pesticides (year 2000)

Pesticides	ADI	ARC	% ADI
EPN	0.00001	0.0000124	124.00
Ethion	0.002	0.0004525	22.63
Prothiofos	0.0001	0.0000099	9.90
Methidathion	0.001	0.0000697	6.97
Carbofuran	0.002	0.0001270	6.35
Monocrotophos	0.0006	0.0000358	5.97
Dithiocarbamates	0.03	0.0016581	5.53
Methamidophos	0.004	0.0001909	4.77
Hexaconazole	0.005	0.0001433	2.87
Chlorpyrifos	0.01	0.0002453	2.45
Carbendazim	0.03	0.000576	1.90
Carbaryl	0.003	0.0000520	1.73
Profenofos	0.01	o.0001589	1.59
Metalaxyl	0.03	0.0004470	1.49
Phorate	0.0005	0.0000072	1.44
Flusilazole	0.001	0.0000118	1.18
Omethoate	0.002	0.0000230	1.15

ARC (Actual Residue Contribution) = $(F_i \times R_i) / BW$

The average daily intake of crop groups by Taiwanese people for risk assessment during the year 2000 has been recalculated according to a 24-hour recall data file. This data file was derived from a 5-year Nutrition and Health Survey in Taiwan (NHSIT) from 1993 to 1996 (Pan *et al.*, 1993-1996). The project was initiated by the DOH. The sample number was 9,962 persons, in the

range 4 to over 65 years of age. Owing to the unreliable recall data for people below 13 and over 64 years old, the reduced sample size was 5,834. TACTRI has categorized hundreds of items into crop groups as shown in Table 2. A summary of the recalculated results is shown in Table 8 (Wong, 2000).

Table 8. Average daily intake of Taiwanese

Crop group	Crop sub-group	Average daily intake (g/person/day)	% of intake
Main food	Rice	178.45	20.42
	Wheat	80.82	9.25
	Pulse	65.29	7.47
	Maize	17.75	2.03
Subtotal		**342.31**	**39.18**
Fruit	Large berries	25.86	2.96
	Small berries	37.79	4.32
	Pome fruits	32.98	3.77
	Stone fruits	12.52	1.43
	Melon	27.10	3.10
	Citrus	58.70	6.72
Subtotal		**194.95**	**22.31**
Vegetable	Broccoli vegetables	63.62	7.28
	Leafy vegetables	143.34	16.41
	Fruit vegetables	12.35	1.41
	Cucurbit	41.41	4.74
	Mushroom	1.82	0.21
	Root & stem vegetables	61.68	7.06
Subtotal		**336.52**	**38.51**
Total		**873.77**	**100.00**

Another purpose for the risk assessment of dietary exposure to pesticides is to evaluate the suitability of the established tolerances in pesticide regulations. The evaluation is based on MPI, Sub-MPI and SMPI.

Taking the dietary intake risk assessment of cyhalothrin as an example (Table 9), cyhalothrin is registered to be used on rice, brossica vegetables, leafy

vegetables, small berries, and pome fruit. The SMPI calculated from the tolerances and the daily consumption of these crop groups is about 0.260 mg/person/day. It was found during the study that the tolerance for cyhalothrin on leafy vegetable, originally set at 1.0 ppm, was below the maximum actual residue of 1.32 ppm. Therefore, the tolerance for cyhalothrin on leafy vegetable was adjusted from 1.0 ppm to 2.0 ppm. This is acceptable because after the adjustment, the SMPI (0.426 mg/person/day) was still below the MPI (1.2 mg/person/day) for cyhalothrin. Another example is dicofol (Table 10). All tolerances of dicofol must be adjusted or the use of dicofol must be restricted.

Table 9. Dietary intake risk assessment for cyhalothrin
ADI: 0.02 mg/kg bw/day (FAO, 1984)
MPI: 1.2 mg/person/day (ADI x 60kg)

Crop Group	Tolerance (PPM)	Daily Consumption (kg/day)	Estimate Intake (mg/day)	Actual Residue (ppm)	Actual Intake (mg/day)
Rice	0.5	0.148	0.074	0.004	0.001
Brassica vegetables	0.5	0.066	0.033	0.42	0.027
Leafy vegetables	1.0(2.0)	0.083	0.083(0.166)	1.32	0.110
Small berries	1.0	0.041	0.041	0.311	0.113
Pome fruit	1.0	0.029	0.029	0.61	0.001
SMPI			0.260(0.426)		0.252

Table 10. Dietary intake risk assessment of dicofol
ADI : 0.002 mg/kg bw/day (FAO, 1992)
MPI: 0.12 mg/person/day (ADI x 60kg)

Crop Group	Tolerance (ppm)	Daily Consumption (kg/day)	Estimate Intake (mg/day)	Actual Residue (ppm)	Actual Intake (mg/day)
Pulses	0.5	0.084	0.042	0.05	0.004
Legume Vegetables	5.0	0.011	0.057	0.5	0.006
Citrus	3.0	0.066	0.198	2.4	0.159
SMPI			0.297		0.169

Multi –Residue Method

Based on pesticide usage survey data, 165 pesticides were selected for investigation to establish multi-residue analysis methods for vegetables, fruits

and rice (Table 11). Three multi-residue methods were developed for the analyses. One could detect 145 pesticides and their metabolites, another could detect 19-triazole pesticides and their metabolites, and the third one is used to detect pesticide residues on rice (Tsai, 1999a)(Tsai, 1999b)(Wong *et al.*, 2000). The results for dithiocarbamate fungicides were generated using a modified Keppel method. A brief flow chart of the first multi-residue method is shown as figure 5. Vegetable samples are extracted with acetone. Clean-up is performed by liquid partitioning from aqueous solution to petroleum ether and dichloromethane, followed by a Florisil column chromatography. The extracts are analyzed by temperature-programmed gas chromatography (GC) with FPD and ECD, HPLC with OPA post-column reaction and fluorescence detection, and HPLC with UV absorption detection. 2-benzimidazole and 4-organonitrogen compounds were subject to extra clean-up steps for fruit samples, before using HPLC-UV. For the triazoles, multi-residue method is shown as a flow chart in Figure 6. Samples are extracted with acetone under basic conditions. The clean-up procedure is the same as used for the first method. The extracts are analyzed by temperature-programmed gas chromatography (GC) with NPD and ECD. A flow chart of the method for pesticide residues on rice is shown in Figure 7. Samples are grounded and distilled water is added. The mixed samples are extracted with n-hexane and mixed with acetonitrile. Clean-up is performed using acetonitrile with n-hexane to remove the fat. This is followed by additional clean-up using a Florisil column. The extracts are analyzed by temperature-programmed gas chromatography (GC) with FPD and ECD, and HPLC with OPA post-column reaction.

Table 11. Pesticides analyzed by multi-residue method

	Pesticide	group	Pesticide		Pesticide name
O.P.	Acephate	Orgeno-	Profenophos	Aromatic nitro	Butachlor
	Azinphos-	phosphorus	Propaphos	compound	Captafol
	Bromopho		Propaphos-SO		Captan
	Bromopho		Propaphos-SO2		Carbendazim
	Cadusafos		Prothiofos		Carpropamid
	Carbophen		Pyraclofos		Chinomethionat
	Chlorfenvi		Pyrazaphos		Chlorothalonil
	Chlorpyrip		Pyridaphenthion		Dichlorfluanid
	Chlorpyrif		Quinalphos		Dicloran
	Chlorthiop		Terbufos		Dicofol
	Cyanofenp		Tokuoxon		Dinocap
	Demeton-s		Triazophos		Endosulfan
	Dialiphos		Trichlorfon		Fenarimol
	Diazinon		Vamidothion		Flufenoxuron
	Dichlorvos	Synthetic	Allethrin		Fluroxypyr
	Dicrotopho	pyrethroid	Alphacypermethrin*		Fthalid
	Dimethoat		Beta-cyfluthrin		Haloxyfop-methyl
	Dyfoxon		Bifenthrin		Hexaflumuron
	Edifenphos		Cyfluthrin		Iprodione
	EPN		Cyhalothrin		Isoprothiolane
	Ethion		Cypermethrin		Kresoxim-methyl
	Ethoproph		Deltamethrin		Linuron
	Etrimfos		Fenpropathrin		Metalaxyl
	Fenamipho		Esfenvalerate		Metolachlor
	Fenamipho		Fenvalerate		Nuarimol
	Fenchlorph		Flucythrinate		Oxadiazon
	Fenitrothio		Fluvalinate		Pendimethalin
	Fensulfothi		Permethrin		Procymidone
	Fenthion		Tetramethrin		Pyridaben
	Fonofos		Tralomethrin		Pyrifenox
	Formothio	Triazole	Azafenidin		Teflubenzuron
	Fosthiazate		Bromuconazole		Tetradifon
	Iprobenfos		Cyproconazole		Thiabendazole
	Isazofos		Difenoconazole		Trifluralin
	Isofenphos		Epoxiconazole		Vinclozolin
	Isoxathion		Fenbuconazole		1-naphthal
	Leptophos		RH9129	Carbamate	3-Keto Carbofuran
	Malathion*		RH9130		3-OH Carbofuran
	Mephosfol		Flusilazole		Aldicarb
	Methamido		Hexaconazole		Aldicarb sulfone
	Methidathi		Imibenconazole		Aldicarb sulfoxide
	Mevinphos		Myclobutanil		Bendiocarb
	Monocroto		Paclobutrazole		Butocarboxin
	Naled		Penconazole		Carbaryl
	Omethoate		Propiconazole		Carbofuran
	Parathion		Tebuconazole		Fenobucarb
	Parathion-		Tetraconazole		Isoprocarb
	Phenthoate		Triadimefon		Methiocarb
	Phorate		Triadimenol		Methomyl
	Phosalone	Aromatic nitro	Alachlor		Metolcarb
	Phosdiphe	compound	Aziprotryne		Promecarb
	Phosmet		Bifenox		Propoxur
	Phosphami		Bromopropylate		Thiodicarb
	Phoxim		Bupirimate		XMC
	Pirimiphos		Buprofezin		

The average recoveries of 90% of the pesticides studied were in the range of 60% to 120%. The average recoveries of the remaining 10% of the pesticides investigated are below 60%. The detection limits of these pesticides were between 0.001 to 0.5 ppm.

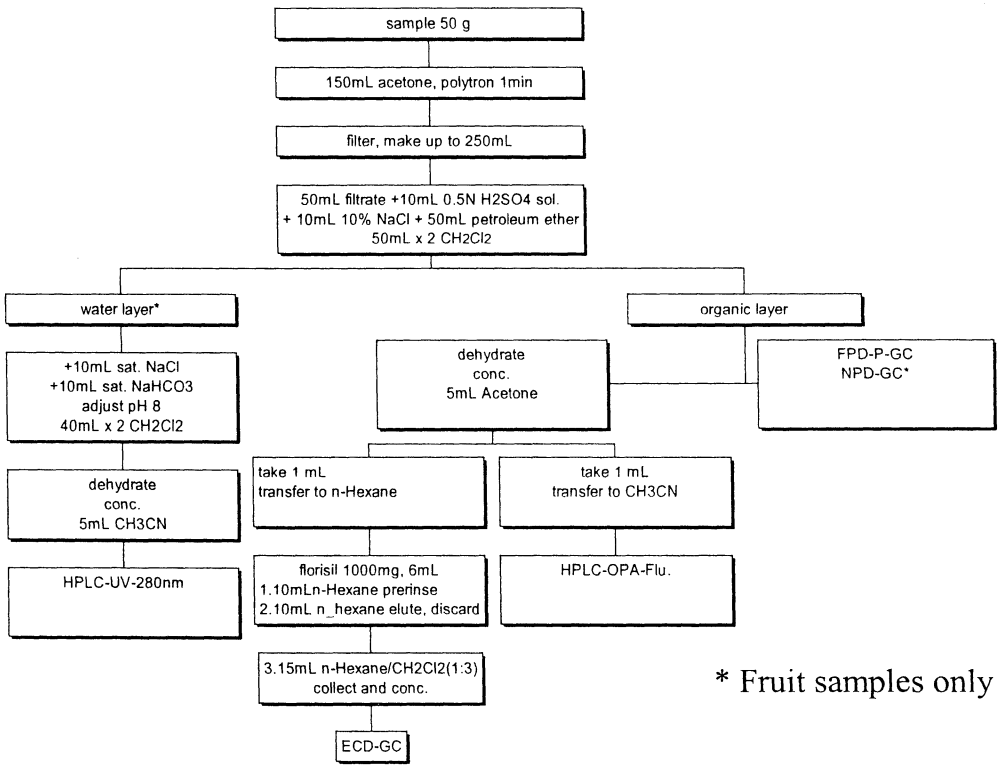


Figure 5. Multi-residue analysis methods- Applied on fruits and vegetables

These multi-residue methods are suitable for rapid screening of pesticide residues in a majority of field or market samples. It takes less than four hours to complete the analysis. One person is able to analyze 8 to 10 samples in a batch, quantitatively and qualitatively.

In Taiwan, these three multi-residue methods are the only methods recommended by the authorities for the screening of pesticide residues on crops. The classification of commonly detected pesticides on crops, based on their chemical groups, is shown in Table 12. No other methods, such as ELISA or other enzyme-based methods are suitable or effective for screening a large number of pesticide residues on fresh commodities.

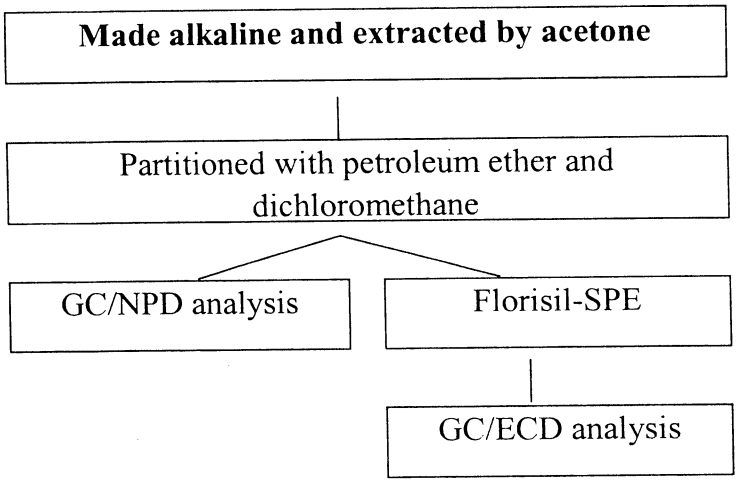


Figure 6. Multi-residues analysis method for triazole pesticides

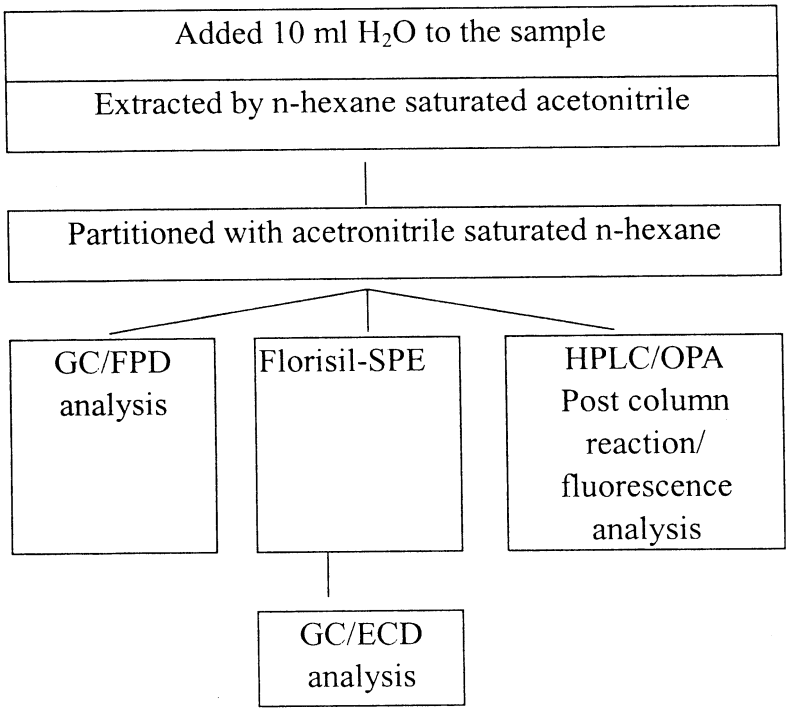

Added 10 ml H_2O to the sample
Extracted by n-hexane saturated acetonitrile
Partitioned with acetronitrile saturated n-hexane
GC/FPD analysis
Florisil-SPE
HPLC/OPA Post column reaction/ fluorescence analysis
GC/ECD analysis

Figure. 7. Multi-residue analysis method for rice

Table 12. Summary of pesticides detected

Commodity	OP*	PY	AN	CA	TR	DT	Total
Rice	6	1	2	7	0	0	16
Fruit	20	10	9	12	13	1	65
Vegetable	14	7	5	8	9	1	44
Total	23	10	10	12	13	1	69

*OP= organophosphorus, PY= synthetic pyrethroid, AN= aromatic nitro compound, CA= carbamate, TR= triazole, DT= dithiocarbamate.

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Management of Pesticide Residues in Sustainable Agriculture

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Abstract

Sustainable agriculture requires the maintenance of the natural resource base and the economic viability of agricultural production. The use of pesticides may contribute to sustainability provided the pre-registration risk assessments pass the hurdles of safety for public health, the environment and trade. Post-registration monitoring should confirm the pre-registration assessment, but we should be alert for unanticipated residues or impacts.

The management of agricultural and animal industries needs special attention where land has been contaminated by previous uses of organochlorine pesticides. Production systems should be organised to minimise the extraneous residues occurring in food and to reduce dietary exposure and risks to trade.

Key words

Pesticide residues, risk assessment, public health, environment, trade.

Introduction

The pesticide registration system provides the opportunity to evaluate risks from the use of pesticides before they are registered and used. Pesticide companies are required to generate extensive data packages designed to satisfy questions about safety. Questions about the impact of the pesticide on the sustainability of agricultural production systems and the impact on ecosystems can often be dealt with in the pre-registration evaluation.

Sustainability of production may be threatened in some instances by soil contaminated with persistent organochlorine pesticides from previous uses. Organochlorine residues in soil can threaten the viability of animal industries because of the resulting residues in meat, milk or eggs.

In this paper I shall discuss:

- definitions of sustainable agriculture
- pesticide specifications
- uses of pesticides and the risks posed by pesticide residues
    - public health risks of residues in food
    - environmental risks posed by residues in soil and water
    - trade risks posed by residues
- residues from previous uses of organochlorine pesticides
- future

Definitions of sustainable agriculture

Clarke and Wylie (1997) drew attention to the variety of definitions of sustainable agriculture. In simple terms, "A sustainable farming system is one which allows the production of food and fibre on a given land area to be sustained at the current level indefinitely." They quoted the Standing Committee on Agriculture Working Party definition (SCA 1991), which elaborates implications and supporting principles of sustainable agriculture.

The SCA Working Party defined sustainable agriculture as: the use of farming practices and systems which maintain or enhance:

- the economic viability of agricultural production,
- the natural resource base, and
- other ecosystems which are influenced by agricultural activities.

The definition was further elaborated with five supporting principles:

1. Farm productivity is sustained or enhanced over the long term.
2. Adverse impacts on the natural resource base of agriculture and associated ecosystems are ameliorated, minimised or avoided.
3. Residues resulting from the use of chemicals in agriculture are minimised.
4. The net social benefit derived from agriculture is maximised.
5. Farming systems are sufficiently flexible to manage risks associated with the vagaries of climate and markets.

We should note that residues are specifically mentioned and that economic viability is part of sustainability.

Pesticide specifications - risks posed by environmental contaminants

Technical grade pesticides usually contain impurities structurally related to the starting materials, reaction products and the pesticide itself. In some cases the manufacturing impurities are environmental contaminants, the levels of which need to be controlled.

FAO defines relevant impurities as those by-products of the manufacture or storage of a pesticide which, compared with the active ingredient, are toxicologically significant to health or the environment, are phytotoxic to treated plants, cause taint in food crops, affect the stability of the pesticide, or cause any other adverse effect (FAO, 2002).

Our interest here is in those impurities that are toxicologically significant to health or the environment. Users may be inadvertently contaminating the farm environment if the pesticide product is formulated from an out-of-specification technical material. Examples of environmental contaminants occurring in pesticides are shown in Table 1.

Table 1. Examples of contaminants occurring in pesticides (Ambrus *et al.*, 2003).

Pesticide	Contaminant
chlorthal-dimethyl	hexachlorobenzene
copper oxychloride	arsenic, lead, cadmium
dicofol	DDT and related compounds
quintozene	hexachlorobenzene
zineb	cadmium

Pesticides evaluated by registration authorities should only be approved for use if they comply with the specifications. Out-of-patent pesticides from various sources need to be checked to ensure they do not contain excessive contaminant levels.

The uses of pesticides and the risks posed by pesticide residues

Before a pesticide is registered or approved for use the authorities must be satisfied that the risks are either minimal or are acceptable with proper management.

The following risks are subject to assessment prior to registration:

–occupational health, i.e. the risks to the user or applicator of the pesticide;

–public health, risks to the consumer of residues in food;

–environmental, risks to non-target organisms of residues in soil and water; and
–trade, risks that residues in raw and processed commodities will be illegal.

The occupational health risk is not generally related to residues, but public health, environment and trade risks are often residue issues.

Public health risks of residues in food

The data requirements and the methods of risk evaluation are more highly developed in this area than in any other (Figure 1).

In risk analysis terminology we may regard the toxicity of the pesticide as the hazard.

The dose response of the pesticide is the hazard characterization.

Consumer exposure is the dose of residue, which is equal to the residue concentration in the food multiplied by the amount of the food consumed.

The risk is then assessed by examining consumer exposure against the hazard characterization.

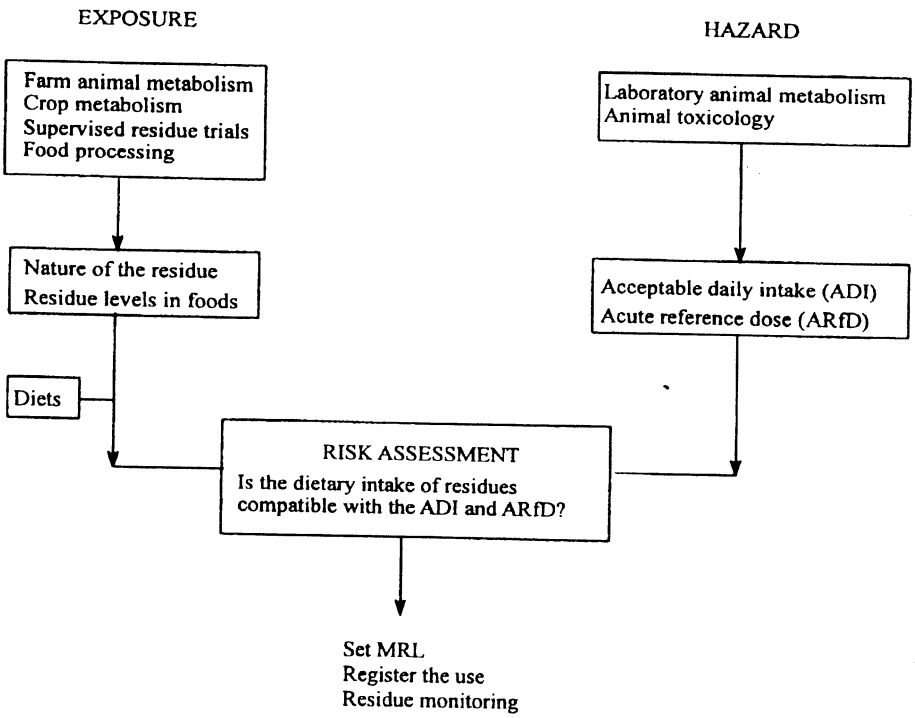

Figure 1. Risk assessment for pesticide residues in food.

Prior to registration extensive data on metabolism and toxicity testing of the pesticide allow the authorities to establish an ADI (acceptable daily intake) and an ARfD (acute reference dose) needed for assessing the acceptability of chronic and short term exposures respectively. (Exposure in this context means

the same as intake).

The no-observable-effect-levels (NOELs) from animal toxicity testing are divided by suitable safety factors (usually 100) to obtain the ADI and acute RfD.

Data on animal and plant metabolism, supervised residue trials and food processing studies provide the information on the residues likely to occur in food when the pesticide is used according to label directions. The residue level in a food multiplied by its consumption gives us the consumer intake or exposure for the residue.

Chronic or long-term consumer intake is compared with the ADI. Short-term intake is compared with the acute RfD. Registration will not proceed if the best estimates of intake exceed the ADI or acute RfD.

Environmental risks posed by residues in soil and water

Registrants provide copious data that allow registration authorities to evaluate risks to the environment (Figure 2)

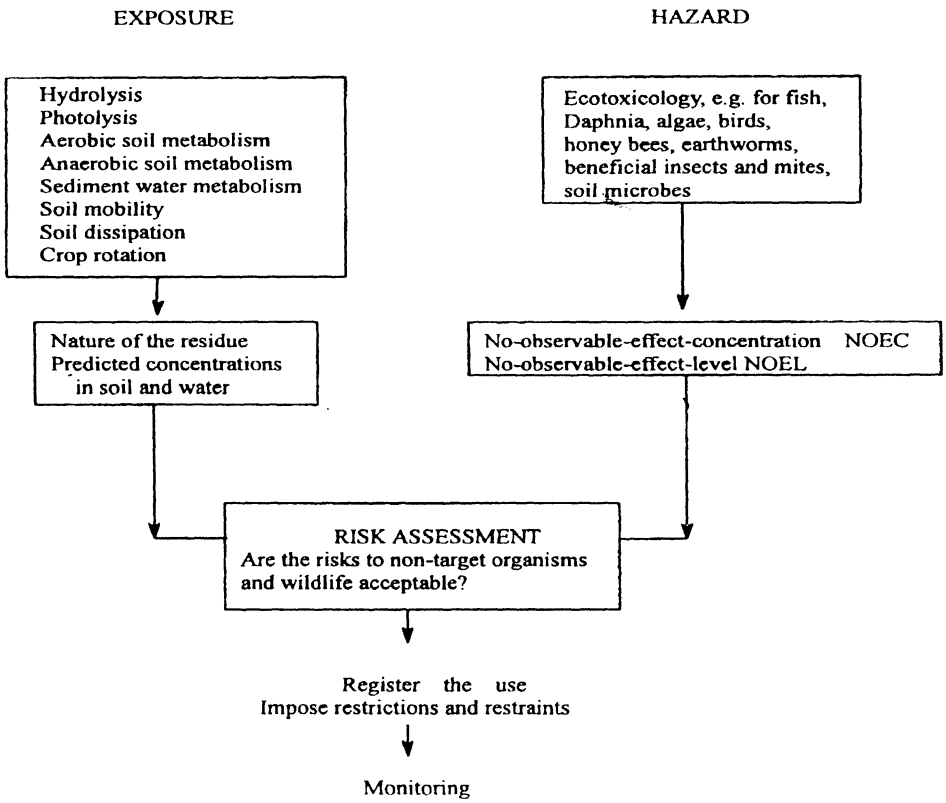

Figure 2. Assessment of risks to the environment resulting from pesticide uses.

We are interested in the persistence and fate of the pesticide and relevant transformation products (metabolites and hydrolysis and photolysis products) in

soil and water and their potential to move off target in run-off or down the soil profile to ground water.

We should be alert for environmental properties that would raise concerns for sustainable agriculture:

- a combination of soil persistence and high leaching mobility increases the risk of ground water contamination.
- a combination of soil persistence and fat solubility increases the risk of residues occurring in farm animals.
- a combination of environmental persistence and high ecotoxicity for a particular species, e.g. Daphnia, suggests a risk to aquatic organisms from runoff.

Registration should proceed only where environmental risks are acceptable.

A particular method of usage that minimises exposure of the environment might allow the use of some compounds that would otherwise be of concern. For example, rodenticides may be used in bait stations that minimise soil contamination and restrict access by other wildlife.

After registration, monitoring should be introduced to check the validity of pre-registration assessments. Ideally the monitoring should target those areas or situations where residues or effects, if they occur at all, are most likely to be seen. But we should also be alert for residues or impacts that might occur but were not anticipated.

Trade risks posed by residues

Trade risk is different from public health and environmental risk because it generally applies only to exports. Trade risk caused by pesticide residues is a serious threat to sustainable agriculture and should be evaluated prior to registration. The nature of the hazards and exposures to trade risks is summarised in Figure 3.

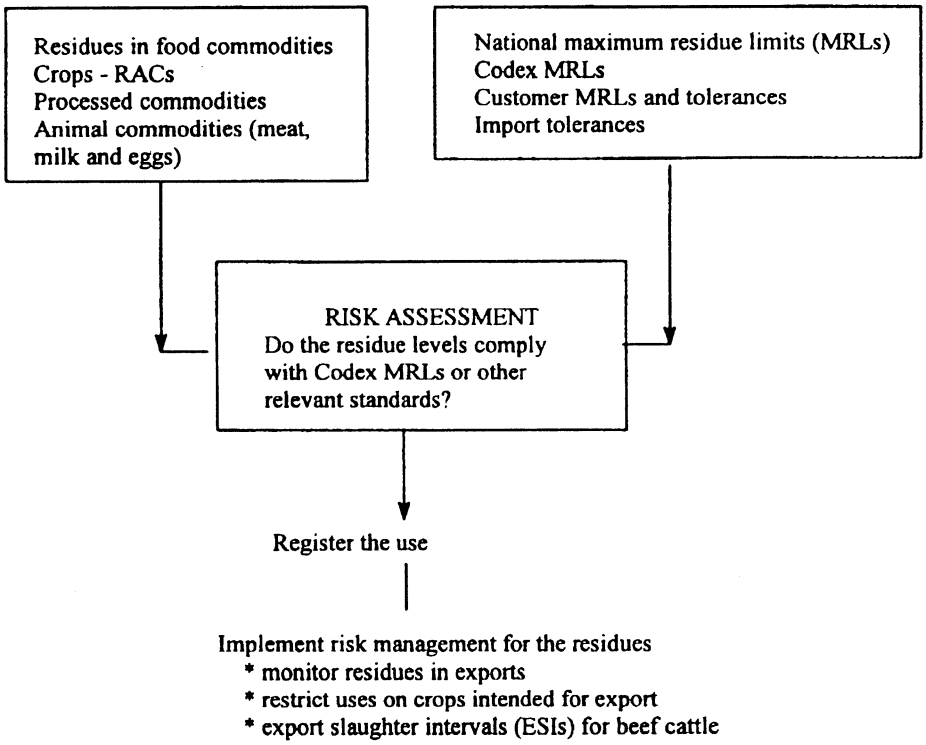
Residues in food commodities
Crops - RACs
Processed commodities
Animal commodities (meat, milk and eggs)
National maximum residue limits (MRLs)
Codex MRLs
Customer MRLs and tolerances
Import tolerances
RISK ASSESSMENT
Do the residue levels comply with Codex MRLs or other relevant standards?
Register the use
Implement risk management for the residues
* monitor residues in exports
* restrict uses on crops intended for export
* export slaughter intervals (ESIs) for beef cattle

Figure 3. Assessment of risks to trade resulting from pesticide residues.

Some industries are particularly vulnerable to trade risks from residues. A pesticide used on only a small portion of the grape crop may result in residue contamination of a large volume of wine because of blending and mixing. This will impact on the trade if the residue is not permitted in the export market.

Beef cattle are also very susceptible to trade problems because their feed may sometimes be by-products of other industries, e.g. fruit, cereals, sugar cane, pulses and cotton, with the attendant residues from pesticide uses in those industries. Pastures may be inadvertently contaminated by spray drift from a neighbouring crop. Furthermore, considerable amounts of soil (1 kg per day) may be directly consumed by a grazing animal, thus exposing the animal directly to pesticide residues in the soil.

Pre-registration risk assessment is valuable for minimising some trade threats but it needs further development. Some trade risks resulting from residues are not amenable to control at registration and must be managed in other ways.

Risk management options for exports include residue monitoring. When

excessive or illegal residues are detected a traceback system should identify the causes. Animals intended for the export market may have to be put on a regime of controlled feed for an interval before slaughter to ensure that the meat complies with the standards of the importing country.

A pest or disease incursion can threaten the sustainability of an industry because of quarantine restrictions on the export of produce from the affected zone. For example, fruit from a fruit-fly infested zone may not be permitted to be sent elsewhere without inspection and pesticide treatment. Industries that cannot meet the requirements will no longer be sustainable. An example of such requirements is: (1) approved post-harvest insecticide treatment, (2) residues to be safe for the consumer and (3) residue levels complying with Codex or customer country standards.

Residues from previous uses of organochlorine pesticides

Previous uses of persistent organochlorine compounds such as dieldrin and DDT have left residues in soil that pose risks to sustainable agriculture. Residues in the soil are likely to result in residues in some crops (e.g. root vegetables) and farm animals that have access to the contaminated area.

First is the risk that the dietary intake might approach or exceed the ADI for these compounds. Second is the risk to trade if the residues in produce exceed the extraneous maximum residue limits (EMRLs) allowed by Codex or training partners. These are both strong reasons to identify contaminated areas and to minimise the possibility of producing contaminated food. For example, farm animals should not be allowed access to old dip sites where organochlorine compounds were used.

The 1994 Australian Market Basket Survey (Marro, 1996) included DDT and dieldrin in the analytes surveyed and included tests on human milk in the diet of infants. The survey showed that infants were the critical population and that their intakes (on a body weight basis) were considerably higher than for other population groups (Table 2).

Table 2. Estimated daily intake of DDT (and DDE and related compounds) and dieldrin residues in μg/kg body weight (from Appendix 7, 1994 Australian Market Basket Survey).

	Adult males	Adult females	Boys aged 12	Girls aged 12	Toddlers aged 2	Infants, 9 months
DDT (total)	0.0174	0.0121	0.0219	0.0195	0.0328	1.4552
Dieldrin	0.0041	0.0041	0.0048	0.0044	0.0070	0.1094

Substantial efforts by government and industry have been made to minimise and avoid organochlorine residues since the uses were deregistered in the 1980s. The incidence of organochlorine residue detections in Australian produce continues to decline. For example, there were only 2 detections of dieldrin (limit of reporting 0.02 mg/kg) in 616 cattle fat samples tested in the 2001-2002 National Residue Survey (NRS, 2002).

Future

Risk assessment procedures and data requirements will be further refined in the light of experience to meet the needs of sustainable agriculture. There will be a wider understanding that pesticide uses will need to pass all the risk assessment hurdles before approval and registration.

New pesticides will be designed to pass the risk assessments posed by registration authorities. The process will encourage the development of "reduced risk" pesticides and withdrawal of support for some old pesticides.

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The 3rd APEC Workshop on Sustainable Agricultural Development

Session 6
Education & Extension in Sustainable

The 3rd APEC Workshop on Sustainable Agricultural Development
16th to 22nd November 2003, Chinese Taipei

Higher Education, Research and Extension Systems in the United States and Chinese Taipei

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Higher Education, Research and Extension Systems in the United States and Chinese Taipei

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Abstract

The higher education systems in both the United States and Chinese Taipei function similarly in teaching, research and extension. The higher education system offers not only baccalaureate degree but also post graduate Master's and Doctor of Philosophy degrees. The land-grant system in the United States was created in 1862 for research in the experiment stations under the Morrill Act and in 1914 for the extension service under the Smith-Lever Act. Agriculture-related research in Chinese Taipei is carried out by Taiwan Agricultural Research Institute, District Agricultural Research and Extension Stations, and academic and private institutions. The extension service in Chinese Taipei, however, is primarily provided by District Agricultural Research and Extension Stations and farmers' associations. Despite the differences in the systems of higher education, research and extension service in the United States and Chinese Taipei, both systems function adequately in assisting farmers in their respective country. The challenges that both systems are facing are discussed.

Keywords: higher education, research, extension service, Morrill Act, Smith-Lever Act, farmers' associations

Introduction

The higher education systems in both the United States and Chinese Taipei function similarly in teaching, research and extension. The systems offer not only baccalaureate degree but also post graduate Master's and Doctor of Philosophy degrees. These degrees may be offered by private or public institutions. Despite the similarities, there are differences in the systems of the United States and Chinese Taipei, particularly in the way the systems established, administered and regulated.

The purpose of this paper is to discuss the higher education systems in the United States and Chinese Taipei and to compare their differences in the activities carried out by the private and public institutions in teaching, research and extension.

The higher education system in the U.S.

The responsibility of providing higher education in the U.S. lies with Universities or colleges in each state. These academic institutions are either public or private funded. Public institutions are primarily funded by states and each usually governed by an institution's Board of Regents. The Board of Regents addresses policy issues relating to the institution and appoints the institution's president to represent the institution and to carry out daily institution-related activities. Private institutions are primarily funded by donations received and tuition collected. Similarly, each private institution is also governed by its own Board of Regents or Directors. The responsibility of the Board is no different from that of a public institution.

1. Roles of U.S. Department of Agriculture (USDA)

USDA is delegated with the responsibility of providing oversight to the higher education, research and extension programs. In early 1990s, the programs were consolidated under the Coordinated State Research, Education and Extension Service (CSREES), which provides funding to states for conducting research, education and extension related activities. USDA implements agriculture-related programs mandated by U.S. Congress. To effectively carry out the mandated programs, USDA establishes partnership with land-grant colleges or universities.

2. Research programs in the U.S.

Agriculture-related research is primarily carried out by land-grant colleges or universities in the U.S. These colleges or universities are parts of the land-grant system, which was established by the U.S. Congress in 1862 under the Morrill Act. Under the act, at least a tract of federal land per state was set aside for conducting agriculturally related experiments. Therefore, there is at least one land-grant college or university per state. Results of the experiments were then transferred to farmers for use in producing agricultural crops. Also under the mandates of the act, federal funds are provided to land-grant colleges or universities for carrying out the experiments.

Since the establishment of the land-grant system, research conducted at the experiment stations has contributed much to the advancement of agricultural technology. However, some deficiencies have also been discovered as a result of 1)

inability of researchers to communicate effectively the research findings to their end users, which are farmers; 2) researchers' unawareness of the problems associating with farming; 3) inability of researchers to properly address farmers' needs; and 4) negative attitudes of some researchers toward farmers' requests for solutions to the problems encountered by farmers in producing agricultural crops. Knowing these deficiencies legislators began to search for suitable solutions to address the needs of farmers.

3. Extension service programs in the U.S.

The extension service system was established by U.S. Congress in 1914 under the Smith-Lever Act. The programs associated with the system are assigned to the land-grant colleges or universities. A county office is established in each county; under which, a number of county agents and extension specialists are hired to 1) digest research data; 2) transform data to language(s) understood by farmers; 3) transfer the information, free of charge, to farmers; and 4) if necessary, conduct applied research aiming at solving problems encountered by farmers in the process of producing agricultural crops. Therefore, the extension service is created to fill the gaps between researchers and farmers. Under the extension service, county agents function as an conduit for channeling information to farmers as county agents are supposed to 1) be able to communicate with farmers in their language(s); 2) understand farmers' needs or problems; and 3) be capable of effectively transmitting information to extension specialists. Extension specialists are hired to work with farmers, county agents and researchers to 1) digest research data and transform them into readable language(s); 2) coordinate problem solving with researchers and county agents; and 3) conduct applied research targeted toward problem solving.

Selected examples of the programs mandated by U.S. Congress and carried out by land-grant colleges or universities
A few selected examples of the programs mandated by U.S. Congress and carried out by land-grant colleges or universities are listed as follows:

Clean water programs, sustainable agriculture research and extension (SARE) programs, integrated pest management, 4-H programs and community leadership development programs.

4. Over the years, the land-grant system is known for its success in 1) providing education in agriculture-related fields, offering undergraduate and post-graduate degrees; 2) training students to meet job market needs; and 3) providing new and cutting edge information and technology to its clients. The success of the system has led the public to have the misconceptions that 1) agricultural products are

grown in supermarkets; hence, are easily available; 2) fruits and vegetables should all be perfect and unblemished; and 3) free service provided by the system is an entitlement; thus not taken it seriously or become overly dependent on the information provided free of charge.

The higher education, research and extension system in Chinese Taipei

1. Roles of the Council of Agriculture,

The Council of Agriculture provides funding for conducting research and extension services at research institutions including TARI, DARES, and various academic institutions and farmers' associations. Unlike USDA, it does not provide direct oversight of the programs. Partnership is, however, established between the Council of Agriculture and the institutions mentioned above enabling it to carry out the programs mandated by the legislature through funding of projects.

2. Higher education system in Chinese Taipei

The higher education in Chinese Taipei is provided by over 160 different universities, colleges and polytechnic institutes. There are currently 6 universities involved in providing agriculture-related higher education, covering all of agriculture-related fields and offering undergraduate and post-graduate degrees.

3. Research programs in Chinese Taipei

Agriculture-related research in Chinese Taipei is conducted in Taiwan Agriculture Research Institute (TARI), Districts Agricultural Research and Extension Stations (DARES), and various academic institutions and private institutions. Funding for research is from various sources, such as institutional budgets, grants from government agencies, and joint programs between public institutions and private industries.

4. Extension programs in Chinese Taipei

The extension system in Chinese Taipei involves TARI, DARES, and various academic institutions and farmers' associations. DARES and farmers' associations serve as the major conduit for the flow of information or technology from government agencies and research institutions to farmers. Undesignated researchers at TARI and extension professors at academic institutions carry out, to a lesser extent, extension related activities to serve farmers.

5. Functions and roles of farmers' associations

The farmers' association system was established while Taiwan was under the Japanese control. This system is consisted of three tier organizations, provincial,

county and township. There is one farmers' association per township; therefore, they are considered an important grass-root, non-governmental organization. Representatives are selected to represent a township farmers' association at the county farmers' association. In turn, representatives of a county farmers' association are selected to represent a county farmers' association to the provincial farmers' association. Functions of a farmers' association include providing services to assist farmers in processing and marketing agricultural products, credits and loans, insurances, and other extension related services.

Conclusion

In spite of the differences in the systems of higher education, research and extension service in the U.S. and Chinese Taipei, both systems function adequately in assisting farmers in their respective country. County agents in the U.S. and employees of DARES and farmers' associations in Chinese Taipei served farmers at the grass-root level. Extension professors in Chinese Taipei serve their clients on a part time basis; therefore, their accomplishments may not be as prominent as extension specialists in the U.S. The systems in the U.S. and , however, face a similar challenge in fighting for adequate resources in order to be more effective in serving their clienteles due to the dwindling resources, which force the cut back of personnel in research and extension programs in both countries. In addition, difficulty also exists in the systems in both countries as to how to effectively carry out research and extension service activities in a coordinated effort to help solve agricultural problems.

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The 3rd APEC Workshop on Sustainable Agricultural Development

Economy Report

The 3rd APEC Workshop on Sustainable Agricultural Development
16th to 22nd November 2003, Chinese Taipei

Integrated Agri-disaster Management for Sustainable Agricultural Development in China

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Integrated Agri-disaster Management for Sustainable Agricultural Development in China

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Abstract

For China, sufficient food with good quality and better life for in 1.6 billion people in 2003 will be of the highest priority for sustainable agricultural development in a short and medium term. To achieve those goals, new technologies for management and rational utilization of agricultural resources, are of great significance. Chinese agriculture under the regime of sustainable development is suffering from natural disasters such as drought, flood and forest fire, etc. very seriously. So how to combat the disasters and to decrease the economic loss with the help from new technologies such as remote-sensing and GIS (geographical information system) has attracted more attentions from governmental officers and scientific researchers. Under the supervision and practical demand for policy-making of Mainstay of Agriculture, the Institute of Natural Resources and Regional Planning, CAAS, P. R. China has developed an integrated agri-disaster monitoring and evaluation system, which is now operationally running with functions like disaster detecting, monitoring, forecasting, economic loss evaluating and providing scientific supporting. In has been proved that this system is very effective in sustainable agricultural development in China.

The 3rd APEC Workshop on Sustainable Agricultural Development
16th to 22nd November 2003, Chinese Taipei

Sustainable Development of Irrigation water in Chinese Taipei

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Sustainable Development of Irrigation water in Chinese Taipei

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Abstract

Taiwan is an island with total area of 36,000 km^2; 70% of the island is approximately covered by mountains and 30% the plains below the elevation of 100 m. Because two-thirds of the island are steep and mountainous lands with relative short courses, 73% of rainfall flows directly into the sea and only less than 30% of water is preserved. Although the average annual rainfall is approximately 2,500 mm, about 2.6 times that of the world, 80% of the rain falls in the wet season, from May to October, which makes it difficult to allocate and utilize the water resources. Owing to the uneven rainfall, irrigation is necessary for crop production, depending on the availability of facilities and the practices of management. In 2001, the total water used in Taiwan amounted to 18.5 billion m^3, of which about 11.5 billion m^3 or 62% of the total was used for irrigation. Since the Tropic of Cancer passes through its middle, the island is characterized by subtropical oceanic zones which allow two or more crops to be grown yearly, wherever water is available. This paper mainly focuses on introducing the aspects dealing with irrigation performance and management prevailed in Taiwan, and some improvements due to the recent environmental and socio-economic changes, for the purpose of sustaining use of irrigation water in Taiwan. Irrigation development is no longer merely a problem of irrigation engineering. The functions and beneficial results of paddy fields and irrigation systems on production, ecology, and livelihood should all be further investigated and evaluated. In order to incorporate with Taiwan's future long-term agricultural policy, some innovative measures for sustainable development of irrigation water in Taiwan should be implemented.

Key Words

Irrigation Association, Irrigation Water, Irrigation

Introduction

Taiwan, an island facing the People's Republic of China across the Taiwan Strait, locates on the west rim of Pacific Ocean. With total area of 36,000 km^2, 70% of the island is approximately covered by mountains and 30% the plains below the elevation of 100 m. The Central Mountain almost extends through the entire length of the island and divides it into two unequal parts of the East and the West coasts.

There are 151 rivers distributing island-wide and only nine of them each possess a basin area exceeding 1,000 km^2. Because two-thirds of the island are steep and mountainous lands with relative short courses, only five rivers possess slopes below 1/1,000 such that 73% of rainfall flows directly into the sea and only less than 30% of water is preserved. Rainfall in Taiwan, situated in the Asian monsoon region, is abundant, but distributing unevenly both in time and space, which is not quite consistent with the growing seasons of crops. The average annual rainfall is approximately 2,500 mm, which is about 2.6 times that of the world, resulting in a total volume of 90.4 billion m^3 of water over the island. However, 80% of the rain falls in the wet season, from May to October, which makes it difficult to allocate and utilize the water resources.

According to statistics of total water use in 2001, total water use in Taiwan is about 18.476 billion m^3, in which 13.012 billion m^3 or 70% is used for agricultural water, comprising irrigation water in the amount of 11.479 billion m^3 (paddy rice irrigation of 8.037 billion m^3, upland irrigation of 3.442 billion m^3), fish-culture water of 1.419 billion m^3, and livestock water of 0.114 billion m^3 as shown in Table 1.

Table 1. Water used in Taiwan, 2001

Unit: $10^6 m^3$

Category\Area	North	Central	South	East	Total	(%)
Agricultural water use	2,284	5,724	2,571	2,434	13,012	(70.42)
(1)Irrigation	2,187	5,122	1,767	2,403	11,479	(62.13)
(2)Fish-culture use	88	557	747	28	1,419	(7.68)
(3)Livestock use	9	45	57	3	114	(0.62)
Domestic water supply	1,973	809	847	95	3,725	(20.16)
Industrial water use	630	503	549	59	1,740	(9.42)
Total water use	4,886	7,036	3,967	2,588	18,476	(100)

Source: Water Resources Bureau, Ministry of Economic Affairs, 2003.

In comparison with the historic statistics, the use amount of agricultural water is cut down year by year, from 16.35 billion m^3 in 1982 to 13.012 billion m^3 in 2001, 21% decrease of range that is 3.34 billion m^3 as shown in Table 2. 88% of agricultural water is used for irrigation, therefore, this paper mainly focuses on introducing the aspects dealing with irrigation performance and management prevailed in Taiwan, and some improvements due to the recent environmental and socio-economic changes, for the purpose of sustaining use of irrigation water in Taiwan.

Table 2. Water used in Taiwan, from 1982 to 2001

Unit: $10^6 m^3$

Year\ Category	Irrigation			Fish-culture use	Livestock use	Agricultural water use
	Paddy rice	Upland	Subtotal			
1982	13,184	864	14,048	2,225	78	16,351
1983	12,649	812	13,461	2,383	88	15,932
1984	11,822	795	12,617	2,380	93	15,090
1985	11,779	780	12,559	2,361	93	15,013
1986	11,402	969	12,371	2,431	100	14,902
1987	11,149	1,006	12,155	2,566	105	14,826
1988	10,677	1,099	11,776	2,793	108	14,677
1989	10,893	1,048	11,941	2,916	117	14,974
1990	11,096	1,032	12,128	3,149	116	15,393
1991	9,379	953	10,332	3,093	129	13,554
1992	9,413	890	10,303	3,064	134	13,501
1993	8,767	946	9,713	2,801	136	12,650

Year\ Category	Irrigation			Fish-culture use	Livestock use	Agricultural water use
	Paddy rice	Upland	Subtotal			
1994	6,888	3,050	9,938	3,097	140	13,175
1995	10,161	1,019	11,180	3,138	146	14,464
1996	7,746	2,453	10,199	3,146	151	13,496
1997	8,398	2,391	10,789	2,583	197	13,569
1998	8,334	2,348	10,682	1,463	109	12,254
1999	7,869	2,554	10,423	1,512	117	12,052
2000	8,165	2,442	10,607	1,584	118	12,309
2001	8,037	3,442	11,479	1,419	114	13,012

Source: Water Resources Bureau, Ministry of Economic Affairs, 2003.

Evolution of Irrigation Development in Taiwan

First Stage (before 1895)

It began about 300 years ago, around China's Yuan Dynasty, when immigrants came from mainland China. Taiwan was still a barren island at that time. As rice is the principal crop for the residents in Taiwan, the irrigation facilities on the island had been developed mainly for rice production in the form of small scale and primitive construction mostly privately owned. Most of the irrigation systems were built and managed by the farmers themselves without any coordination among the water users and supervision by the government at all. Because of the sparse population and the plentiful water, about 200,000 hectares of farmlands had been under irrigation by 1895 without any further management and, therefore, no need to restrict water use.

Second Stage (from 1896 to 1945)

During the period of Japanese occupation of the island, a set of rules and regulations calling for the registration of those private irrigation systems were promulgated by the Japanese government in order to put them under government supervision for well management and maintenance, and 181 public canal cooperatives were founded to take in charge for irrigation operation and management. In the meantime, the government canal cooperatives were also established for operation and management of those canals, which were constructed by government. Later on, the Japanese government further reorganized the public canal cooperatives and government canal cooperatives

into irrigation cooperatives. In this period, the existing systems were remodeled, consolidated, and enlarged, as well as plenty of new systems such as Tao-yuan Canal, Chia-nan Canal, etc. were constructed. The irrigation area was increased to about 560,000 hectares

Third Stage (after 1945)

Due to the devastation in the period of World War II, the irrigation area in Taiwan was reduced sharp to 260,000 hectares. After the Taiwan's recovery from Japanese occupation, the main irrigation works were concentrated on rehabilitation of existing facilities and followed by resumption of all unfinished pre-war projects with the government's subsidies. First of all, rehabilitation of the damaged irrigation systems were the important works to be done, and about 260,000 hectares of irrigation area were rehabilitated. Since 1956, some new development for economical utilization of water resources projects related to irrigation for agricultural production were conducted. The new development projects covered: (1) large-scale irrigation, such as Shih-men Canal irrigation system, Kuan-shan Canal irrigation system, Lu-yeh Canal irrigation system etc., (2) multi-purpose reservoirs, such as Shih-man Dam, Tseng-wen Dam, Min-teh Dam, Pai-ho Dam, etc., (3) groundwater development, mainly developed in Yun-lin and Ping-tung area, and (4) tidal land and river-bed land reclamation. By 1962, the irrigation area was increased to 676,384 hectares, which was the highest record in Taiwan then. For the efficient utilization of the existing water resources, rotational irrigation practice, canal lining project, land consolidation projects were implemented.

Irrigation Organizations and Operation

In the early stages of irrigation development in Taiwan, relevant facilities were constructed by the private sectors. However, due to the lack of effective management, disputes over water use were not unusual and water resources were used rather ineffectively. Consequently, irrigation organizations were formed and established to resolve such conflicts and to improve the water management efficiency, for the purpose of effective utilization of the potential water resources. The government later on intervened and granted these irrigation organizations the status of public juridical person to advance their operation and management capabilities.

Features of Irrigation Associations

According to the General Rules Governing in Organization of Irrigation Associations, the 17 irrigation associations, under the supervision of the Council of Agriculture, are legal and organized by farmers and take the following six

major responsibilities:

A.Construction, improvement, maintenance, and management of irrigation and drainage facilities;

B.Prevention and rescue of disasters/damages to the irrigation and drainage facilities;

C.Fund raising and foundation establishment for the needs of irrigation undertakings;

D.Research and development of irrigation and drainage benefits;

E.Support to relevant government policies in connection with the land, agriculture, industrial policies and rural reconstruction; and

F.Other activities as legally designated by the competent authority.

The 17 Irrigation Associations have been generally established in accordance with local geographical conditions and economic benefits. And their official titles were given according to the major regions that they are servicing, or the river/canal systems. Currently, the 17 Irrigation Associations, with their respective locations shown in Fig. 1, have been entitled the public juridical persons as already mentioned previously. In order to perform the legally prescribed duties, the organizational setup of a typical irrigation association may include: Chairman, the highest official in the organization; the General Manager who is next in command and responsible to the Chairman; the Chief Engineer, along with the level of the General Manager; and eight divisions, running the business right under the supervision of the General Manager. The eight divisions and offices as well as respective sections thereof may be described as follows:

1.Engineering Division: Design section; Construction Section and Evaluation Section;

2.Management Division: Mechanic and Electricity Section; Irrigation Section; and Supervision Section;

3.Finance Division: Revenue Section; Property Section; and Adjustment Section;

4.Administrative Division: Document Section; General Affairs Section; and Cashier Section;

5.Audit Office: Budget Section; Accounting Section; and Statistics Section;

6.Personnel Office: Assignment Section and Rating Section;

7.Security Office: First Section and Second Section; and

8.Computer Office.

Another three offices out of the headquarter, also under the General Manager, are the Management office, Working Station and Irrigation Group. All the field activities, including operation and maintenance (O&M) in the fields of the service areas and association-owned facilities, are carried out by the local

regional management offices, the so-called "working stations", assisted by irrigation groups in their service areas respectively. Besides, some Irrigation Associations have water source and canal working stations which are in charge of controlling and supplying the water. A typical organizational structure of irrigation association is schematically shown in Fig. 2.

Irrigation Operation

Prior to the irrigation season, a preliminary water distribution plan is to be worked out by the management division at the head office according to the government policy, production goals, the existing reservoir/ponds storage and water release, water flows at diversion weirs, other available water sources, past records of irrigation requirements, canal conveyance losses, rotational irrigation intervals, and time of irrigation etc. The prepared plan is handed through regional management offices or directly to the working stations for further study and discussions with irrigation groups, and finalization.

The finalized water distribution plan is to be strictly carried out by the working stations. The canal operators of stations are in charge of regulation and controlling water flows along main canal, laterals, and sub-laterals. The irrigation supervision are in charge of water control and measurement at turnout gates on laterals or sub-laterals, and of inspection on farm-level water distribution which are undertaken by irrigation groups in their individual irrigation areas. Till the year of 2001, the total irrigation area managed by the Irrigation Associations is 374,451 hectares, and the total length of the leading, main, lateral, and sub-lateral canals, and farm supplying ditches is 44,399 km. Especially, the length of farm supplying ditches is 30,870 km., around 70% of the total. The average length of supplying ditches per hectares is 82 meters.

Presently, 81.14% of irrigation water in Taiwan was diverted from rivers, 10.89% from reservoirs and various ponds, 5.42% pumped from groundwater, and 2.55% from other sources.

Irrigation Situation Nowaday

Since the Tropic of Cancer passes through its middle, the island is characterized by subtropical oceanic zones which allowing two or more crops being grown yearly, wherever water is available. Since rice is the staple food in Taiwan, irrigation has been essentially developed for rice cultivation.

Cropping Patterns

Since rice is the predominant crop in Taiwan, it is usually used for the determination of the most common cropping patterns according to the availability of irrigation water. The cropping patterns commonly adopted in Taiwan may be classified into seven groups including: (1) double rice cropping system, (2) single rice cropping system, (3) one rice crop in two year cropping rotation, (4) one rice crop in three year cropping rotation, (5) two rice crop in three year cropping rotation, (6) the year-round growing system for perennial crops, and (7) upland crop rotation system, as illustratively shown in Fig. 3. Of the total area of 374,451 hectares served by the 17 Irrigation Associations in 2001, the double rice-crop area was 185,567 hectares, the single rice-crop area, 22,340 hectares, the rotation cropping area (including two and three year rotation), 81,987 hectares, and the upland crop area, 10,631 hectares

Continuous Irrigation

Taiwan was a barren island in the old day. When immigrants came from mainland China and settled, agricultural activities started and canals were built to convey water from streams for irrigation. During this period, the population was spare and the water was plentiful, there was no need to restrict water use. The irrigation practice in those days was of the continuous method. Starting with the transplanting of rice, the paddy field is continuously supplied with water of 50 mm to 60 mm in depth through the period of rice plants except weeding, fertilizer application and harvesting. Water is applied day and night flowing into the paddy field at one end and out at the other end without any control. Such practice results in high consumption of water. In general, the irrigation rate was as low as 330 hectares/cms in most area.

Rotational Irrigation

Due to the rapid growth of population, development of industry, and the expansion of irrigated areas in 1950, the water use of cultivable lands and existing water resources for irrigation and other objects was approaching to a limit. To develop new water resources is not only costly but also time consuming. In order to reduce the unnecessary waste of continuous irrigation, the government actively initiated the promotion of "Rotational Irrigation Practice" and thus directed the irrigation management into a scientific level in 1956. Three main types of rotational irrigation popularly prevailed in Taiwan are described as follow cases:

Case A: Rotation by sections in the main canal, the water is conveyed in turn to different sections of the main canal.

Case B: Rotation by sections in the laterals or sub-laterals, the main canal keeps continuous flow while water is conveyed to the various sections of laterals or sub-laterals successively.

Case C: Rotation by farm ditches, the water flowing in the farm ditches are intermittent while the flow in the main, laterals and sub-laterals are kept continuous.

In order to facilitate this method of irrigation, the irrigation system is designed to simultaneously deliver irrigation water into each individual "rotation area" of about 50 hectares. Each rotation area is subdivided into five or six rotation units of about 10 hectares each in size. Every rotation area is provided with one turnout gate, one measuring device, and several division boxes as shown in Fig. 4. Water flowing through the turnout is measured and rotated among the rotation units within the rotation area with the amount of water and interval of irrigation adjusted according to the actual rotation unit size, soil, effective rainfall and conveyance losses.

In the aforementioned three types of rotational irrigation, the water is allocated appropriately to farmers in order and time lapse such that various crop fields may get the necessary amount of water respectively, in which case A or B is mostly suitable for drought period, while case C is usually applied in practical irrigation. According to the experiment and practice, rotational irrigation could save about 20-30% in water without producing any bad effect on rice growth and harvest such that the irrigation rate could be increased up to 800 hectares in a cubic meter per second; furthermore, plant growth, fertilizer saving, and elimination of water dispute could be achieved.

Land Consolidation

Since land holdings in Taiwan have been very small and fragmental, the irrigation operation and management is inconvenient due to the inadequate and insufficient irrigation and road systems. A land consolidation program was started in 1958 to amalgamate the small and irregular farm plots and consolidate them by exchange and redistribution of farm roads, and irrigation and drainage systems were made for better transportation, direct irrigation and effective drainage, thereby improving farm level structures. A typical rotational area and water distribution system through land consolidation program is shown in Fig. 5.

As to the water distribution on paddy fields with land consolidation, irrigation water flows continuously through the turnout gate and controlled by

the measuring devices into the rotation area, and irrigation is rotated among rotation units. In the land consolidation area, each block area of about 10-14 hectares is regarded as a rotation unit, and each rotation unit is subdivided in several plots with area of 0.2 hectares –0.4 hectares, about 100-120 m long and 20-40 m wide. Irrigation water is delivered to each plot from the farm supply ditch directly, while in the rotational area without land consolidation, the water is supplied to the plot passing from field to field. Up to 1998, the total completed area is about 380,000 hectares

Problems Encountered

As rice is the predominant crop in Taiwan in the early stage, paddy is grown wherever possible, so, there had been a surplus crop of rice production year after year. For example, the paddy harvested area was 502,018 hectares with an annual brown rice production of 639,000 M.T. in 1945, increased to a high record of 786,343 hectares with a maximum production of 2,712,000 M.T. in 1976.

Moreover, consumption patterns have been changing with increasing wealth, the average year consumption of rice per person has fallen from 134 kg. in 1974 to 59 kg. in 1996. In addition, the international price of rice has been low, and there has never been a fixed export market for Taiwan's rice. In order to balance out production and marketing of rice, a paddy diversion program was initiated in 1984 to divert the use of paddy field from the production of rice to alternative crops. The total diversified paddy field (including set-aside field) was from 43,700 crop-hectares in 1984, increased to 260,000 crop-hectares in 1997. Under this program, theoretically, there should have a large amount of irrigation water to be saved for other use.

Actually, about 76% of the irrigation water is river off-take with local and time difference, and has been seriously polluted, which is very difficult to be used by other users. Besides, the diversified paddy field is not concentrated, and irrigation is still needed for those paddy fields which have not been diversified, and for the upland crops fields, so a certain amount of discharge in canal is necessary for canal conveyance loss. As a result, not only no more water can be saved for other users, but also the irrigation management becomes more complicated. At the present stage of economic growth in Taiwan, water demand has been increasing and the production of additional new water sources has become more costly. No new irrigation projects can be implemented for rice production due to economic feasibility factors. However, in order to maintain paddy field with area of about 350,000 hectares for self-sufficiency in food-crop products so as to ensure the security of food supplies and raise

farmer's income and to narrow the income gap between farmers and non-farm workers, irrigation is still necessary. A certain amount of water is needed to be used for irrigation, but the percentage is decreased year after year. For example, the total amount of irrigation water used in 2001 was about 11.5 billion m^3 or 62% of the total water used in Taiwan, which was much lower than the amount of 13.6 billion m^3 or 81% in 1971.

Prospection

With the increase demand on water for the increasing of population and the expansion of industrialization and urbanization in the last decade, as well as its lower production value per unit use of water, the irrigation water sources in Taiwan is facing the pressure of competition usage from other objects. The acquisition of new water supplies for agricultural irrigation has been become more difficult and costly. However, irrigation water resources are not only essential for agricultural production but also featuring with maintaining the ecological functions. In order to incorporate with Taiwan's future long-term agricultural policy, the main measures for sustainable development of irrigation water in Taiwan are summarized as following:

A. The establishment of a compensation mechanism for transferring of the irrigation water for other purposes should be directed in order to support the water demands of other use objects. The various models on reasonable water use in different areas and different seasons have to be established.

B. In response to raising the use efficiencies and benefits of irrigation water resources, efforts should be made for strengthening improvements in irrigation management and operation techniques, repairing and improving the old existing irrigation system facilities, promoting the pipeline irrigation for upland crops, and providing guidance for the diversification undertakings of the irrigation associations.

C. Accompanying with the development of electronics, the adoption of remote control facilities have to be taken on the irrigation facilities in view of minimizing water loss in canals, monitoring of irrigation water quality in the heavy polluted areas and saving management manpower.

D. Irrigation development is no longer merely a problem of irrigation engineering. The functions and beneficial results of paddy fields and irrigation systems on production, ecology, and livelihood should all be further investigated and evaluated, so as to generally reflect the real value per unit use of irrigation water to the community.

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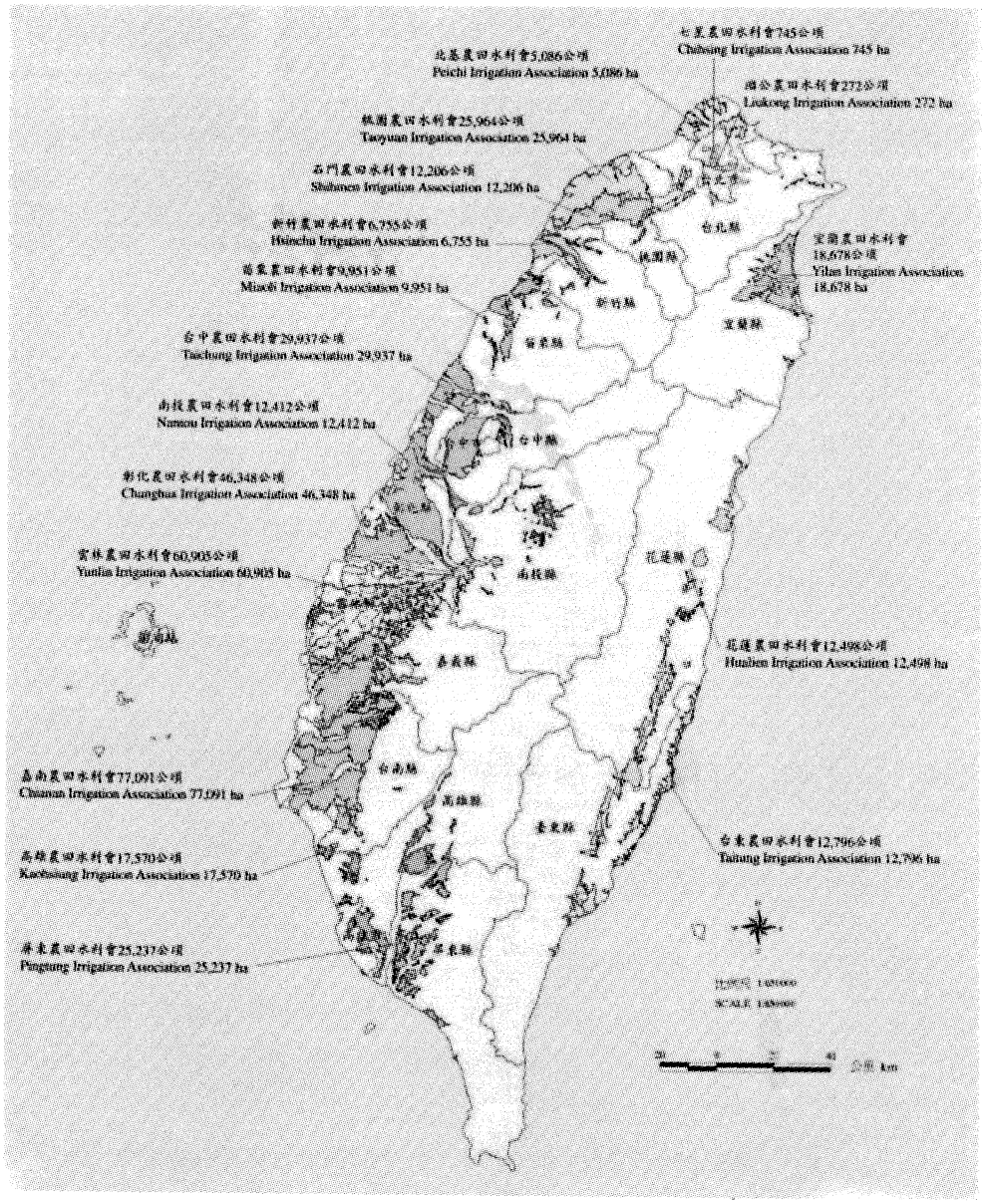


Fig.1. Locations of Present Irrigation Associations and Their Irrigation Area in Taiwan

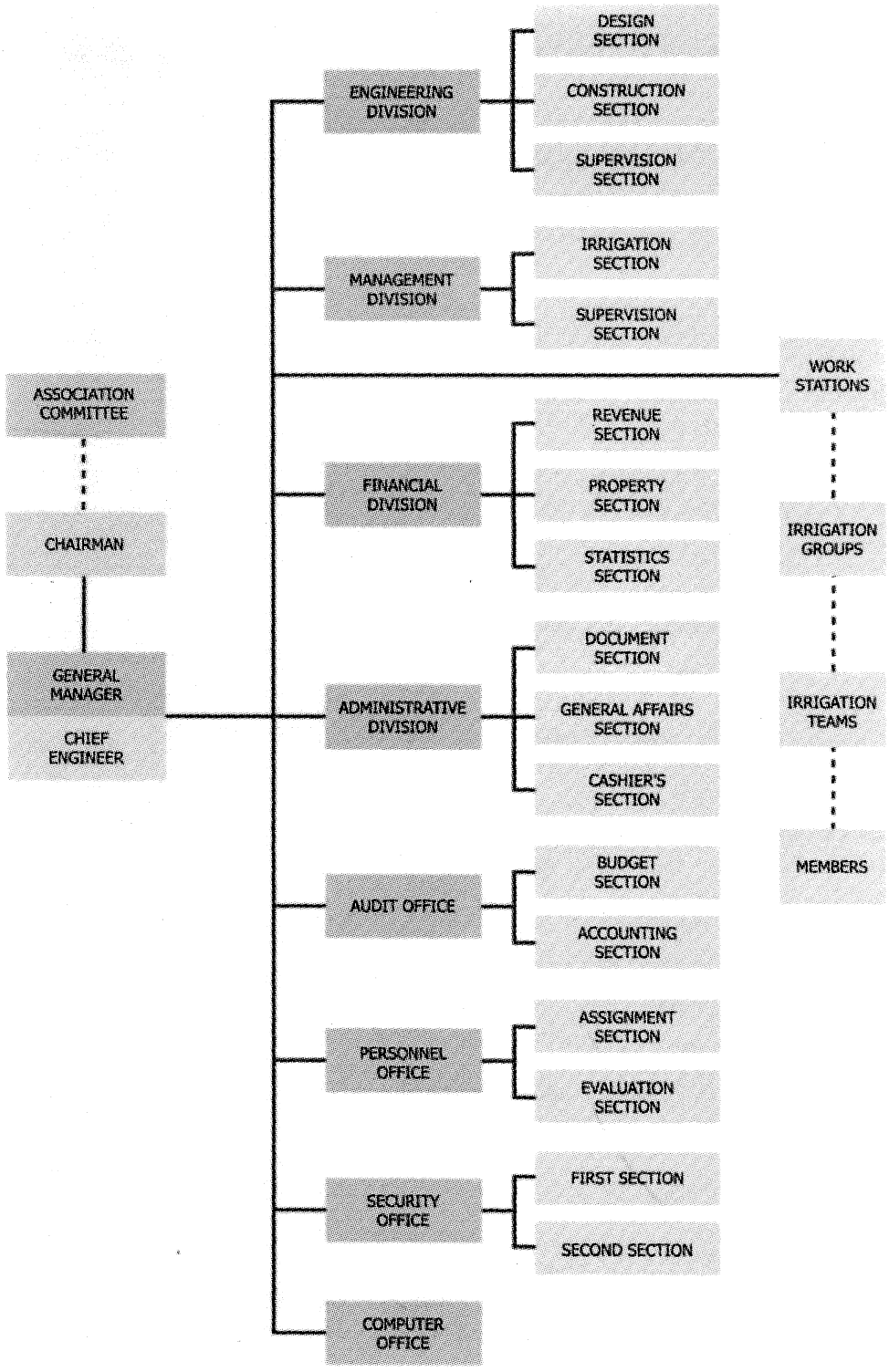
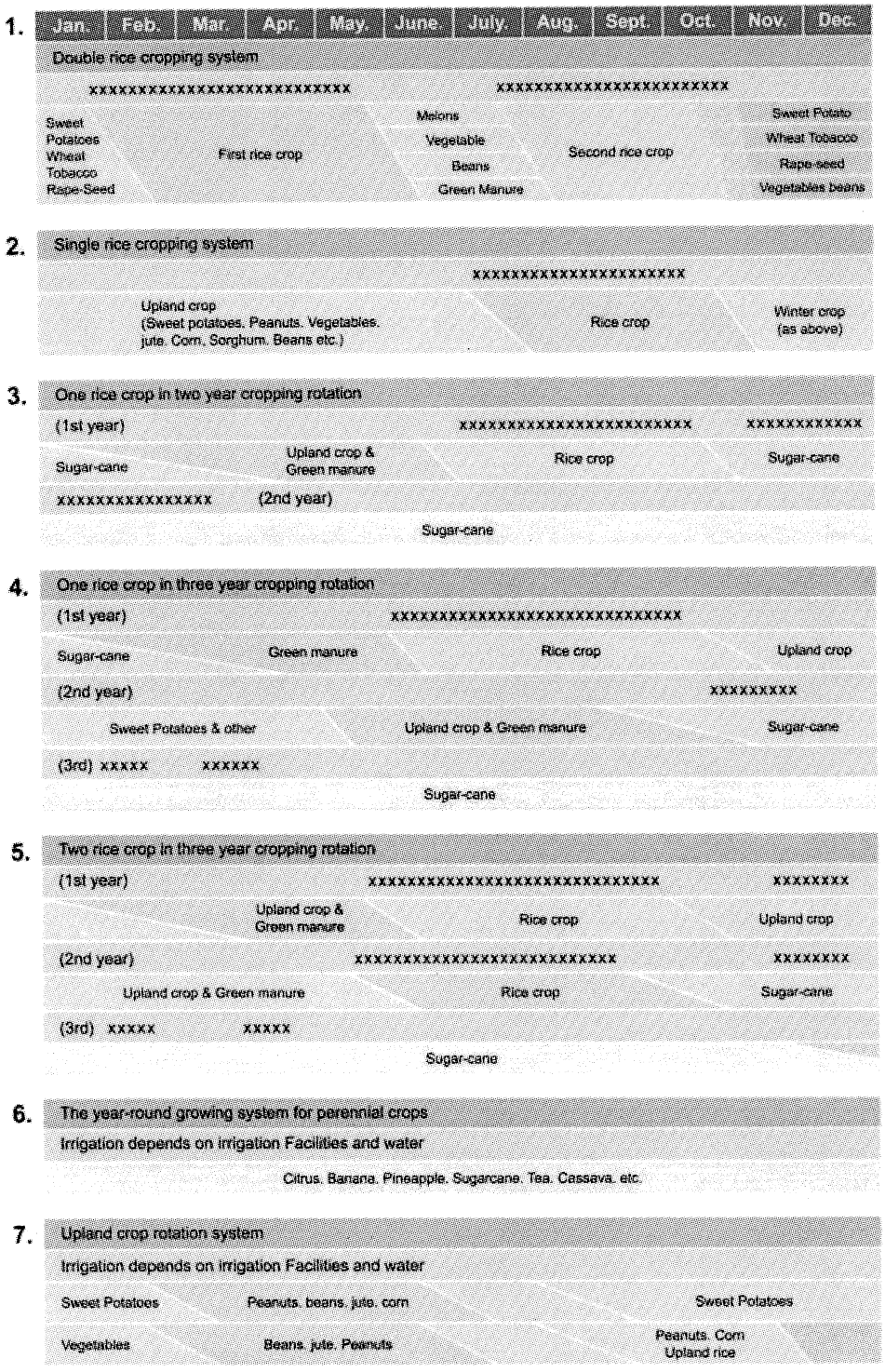


Fig.2. Irrigation Association's Organizational Structural Chart



Legend: "xxx" indicate irrigation period
(Source: L.J. Wen)

Fig.3. Various Cropping Patterns adopted in Taiwan

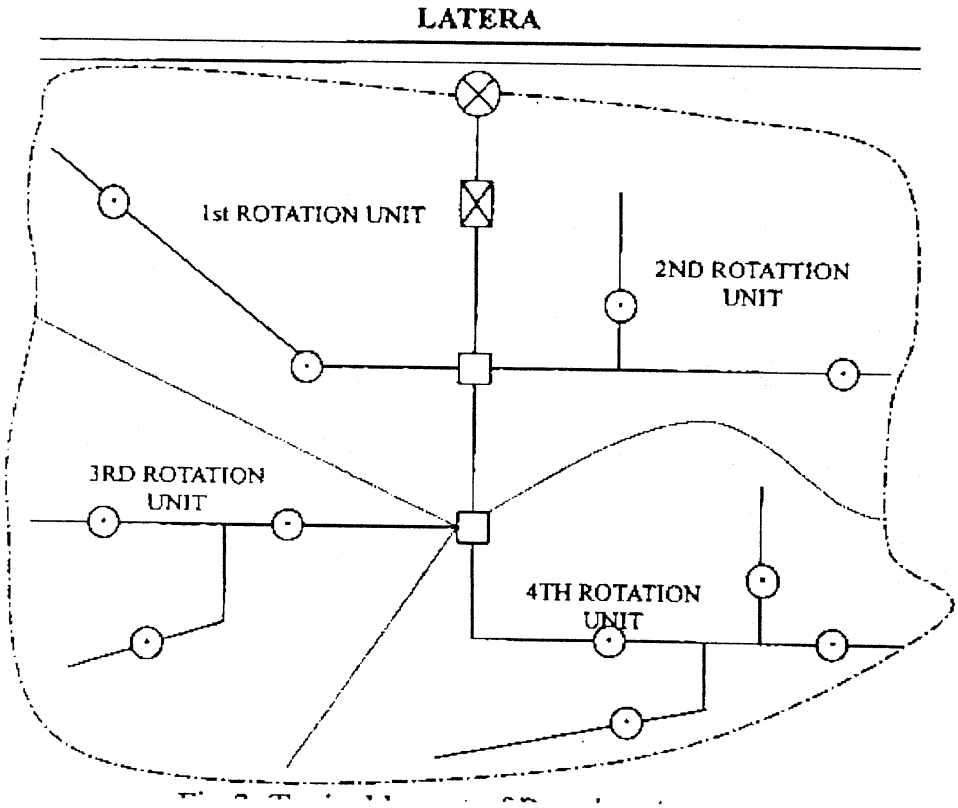


Fig.4. Typical Layout of Rotation Area

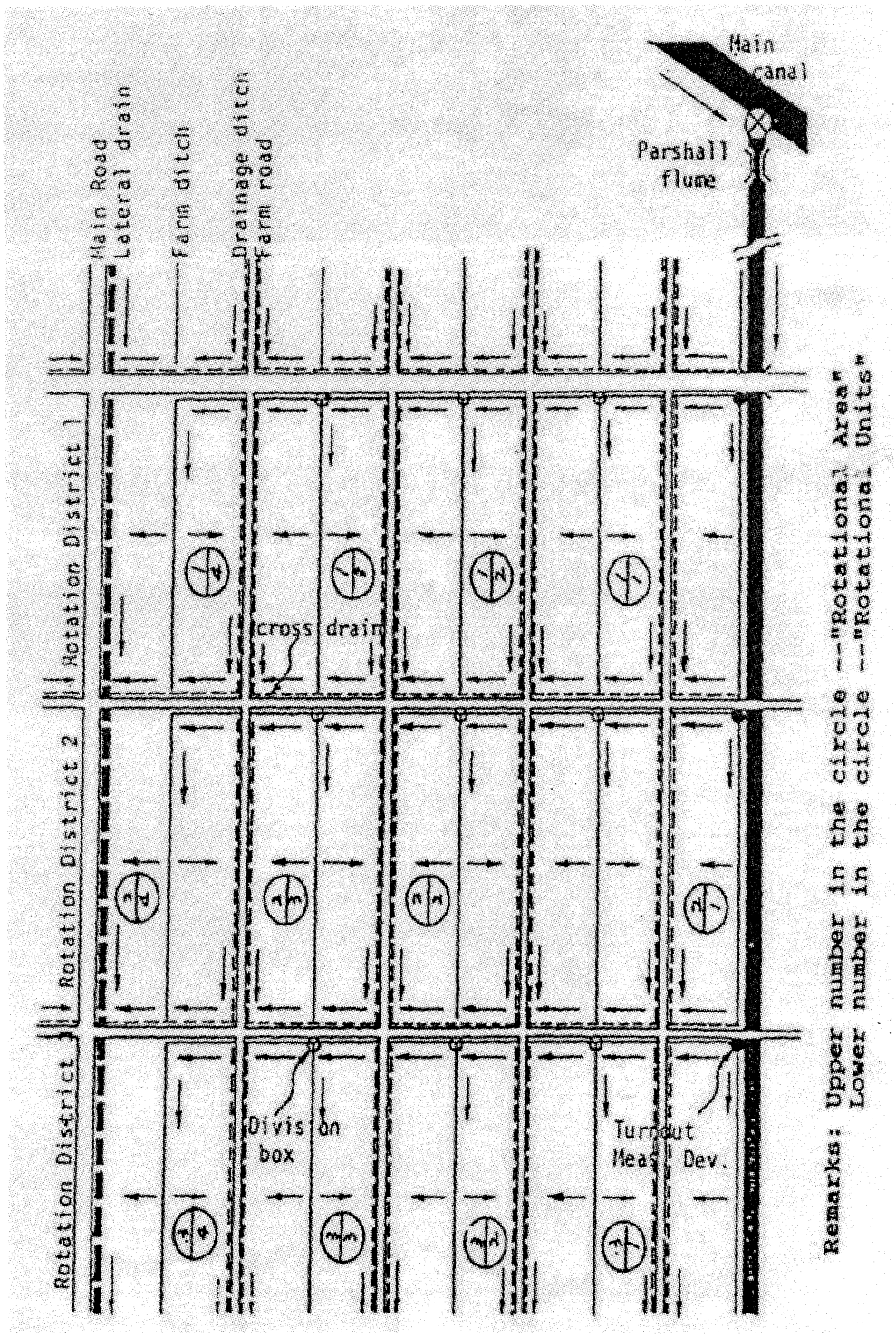


Fig.5. Typical Rotational Area and Water Distribution System through Land Consolidation

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Non-pesticide Methods for Controlling Plant Diseases and Insect Pests in Chinese Taipei

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Abstract

Located in subtropical area, Taiwan has warm and humid climate that is suitable for the occurrence of plant diseases and insect pests. Farmers in Taiwan were used to controlling diseases and insect pests with pesticides that might result in problems of chemical residue, pesticide resistance and environmental pollution. In order to minimize the negative effects caused by the use of pesticides, plant protection institutions have started intensive researches and extensions of non-pesticide methods since early 1970's. The top authority of plant protection, Council of Agriculture (COA), has set the development and extension of non-pesticide methods as a national strategic plan since 1984. With the efforts over the past few years, we have promoted awareness of non-pesticide control, and brought many techniques into extensive application resulting in satisfactory outcomes.

Previously, we experienced considerable success in adopting non-pesticide measures to control insect pests. Among the most well known cases are introducing exotic parasitic wasps to control coconut leaf bud beetle and citrus plant lice, releasing indigenous parasitic wasps to control Asian corn borer. In recent years, some exotic predatory mites have been introduced into Taiwan and tested for their effectiveness of controlling spider mites, and exotic parasitic wasps were introduced to be tested for controlling silver leaf white fly that invaded Taiwan in 1989. Besides, indigenous natural enemies including parasitic wasps, green lacewing, and flower bug have been tested for their effectiveness of controlling different insect pests and some of them were considerably effective. Techniques for mass rearing of the promising natural enemies have been invented or improved that will make the extensive application of the biocontrol agents possible. Other non-pesticide methods that have been carried out in Taiwan include using sex pheromones to control cotton worm, beet army worm, diamond-back moth, sweet potato weevil and smaller tea tortrix, use of methyl eugenol and cuelure 〔4-(p-acetoxyphenyl-2-butanone)〕 mixed with insecticides to annihilate male oriental fruit fly and melon-fly, respectively, hanging yellow sticky cards to catch small insect pests such as white flies, thrips, leafhoppers and aphids. With regard to plant diseases, although its initiation was later, we have gained remarkable achievements. For example, controlling soil-borne diseases of high-value crops by steam sterilization, producing

pathogen-free propagating materials of banana, citrus, asparagus beans, etc. to prevent systemic diseases, especially that are caused by viruses, control of plant diseases with antagonistic microorganisms such as *Trichoderma* spp., *Bacillus subtilis* and *Streptomyces saraceticus*, control of plant parasitic nematodes with the amendment of LT-M mixture into soil, control of several fungal and bacterial diseases with the amendment of SH mixture and an organic compound, FBN-5A, mixed with BVB NO. 4 medium. Moreover, the use of resistant rootstocks for the control of soil-borne diseases also resulted in a success. By using loofah as rootstock, *Fusarium* wilt of bitter gourd is effectively controlled, and by using eggplant as rootstock, bacterial wilt of tomato is satisfactorily prevented. Genetic engineering has been applied to develop transgenic plants resistant to viral diseases in Taiwan. Field trials showed that 3 coat-protein transgenic papaya lines provided a broad-spectrum resistance to different *Papaya ringspot virus* strains originated from Hawaii, Thailand, and Mexico. Genetically-engineered mild strains of viruses were generated to control virus diseases by cross protection. Several projects supported by National Science Council or Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ), Council of Agriculture, aiming at developing transgenic plants resistant to different kinds of diseases are in progress.

Keywords: Non-Pesticide control, natural enemy, sex pheromone, steam sterilization, antagonistic microorganisms, transgenic papaya, genetically-engineered mild strain.

Introduction

Chemical pesticides have long been regarded as the most convenient and effective materials for the control of plant diseases and pests. Although the use of pesticides is unavoidable, high amount of consumption not only wasted money but also caused a lot of problems including chemical residue in foods, environmental pollution and adverse effects on ecosystem. Therefore, developing and applying non-pesticide methods as alternative to chemical control of plant diseases and pests has become a global trend. Located in subtropical area, Taiwan has warm and humid climate that is suitable for the occurrence of plant diseases and insect pests. Farmers in Taiwan are used to controlling diseases and pests with pesticides. In an era of increasing consciousness for food safety and environmental protection, the top authorities of plant protection, Council of Agriculture (COA), has set the development and extension of non-pesticide methods as a national mission in terms of plant protection since 1984. With the efforts through years, we has promoted awareness of non-pesticide control, and brought many techniques into extensive application resulting in satisfactory outcomes. This paper states the development and extension of non-pesticide methods for controlling plant diseases and pests in Taiwan.

Non-Pesticide Control of Insect Pests

Use of natural enemies

In Taiwan, natural enemies of plant insect pests have been used for biological control since early 20th century. Starting in 1947, an indigenous parasitic wasp, *Trichogramma chilonis* (Ishii) (Hymenoptera, Trichogrammatidae), had been studied for its effectiveness of controlling gray borer, stalk borer and shoot borer of sugarcane and has been extensively released since 1972 to sugarcane fields resulting in successful control (COA, 1996). However, extensive studies on biological control had not been common until early 1970's due to the prevalence of chemical control. Natural enemies that interest Taiwanese researchers, especially those who work at Agricultural Research Institute (TARI), include exotic and indigenous ones in terms of their origin. Many kinds of exotic natural enemies have been introduced into Taiwan and tested for their effectiveness of controlling domestic insect pests. Some of them performed well as control agents, whereas some of them failed to establish (Lo, 2002). The information concerning the introduction of exotic natural enemies is summarized in Table 1. In recent years, the natural enemies that have commonly been studied and applied in Taiwan included parasitic wasps, predatory mites, green lacewing, and flower bugs. Some of them have been extensively applied with satisfactory results and some of them are still limited to small-scale field trials.

1.Parasitic wasps

Citrus plant lice, *Diaphorina citri* (Kuwayana) (Homoptera: Psyllidae), is a vector of citrus Likubin in Taiwan. Data showed that it could be effectively controlled by nymphal parasitoid, a parasitic wasp, *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae), in Reunion Islands. The parasitic wasp was introduced into Taiwan to control citrus plant lices. A total of 64 adult parasitoids in 4 shipments were obtained from 1983 to 1986 and subsequently a total of 21,164 adults of *T. radiata* were propagated and released to 39 citrus groves and common jasmine orange (*Murraya paniculata* Jack. var. paniculata) bushes in 12 counties during 1984-1988. Survey data showed that the wasp has successfully established in this island and kept citrus plant lice at low density (Chien *et al.*, 1989).

Coconut leaf bud beetle, *Brontispa longissima* (Gestro) (Coleoptera: Chrysomelidae) was a serious pest of coconut palm in Taiwan during early 1980's. Its larval and pupal parasitoid, a parasitic wasp, *Tetrastichus brontispae* (Ferr.) (Hymenoptera: Eulophidae), was introduced into Taiwan from Guam in November 1983. A total of about 143,082 adults were released by 106 times to Kaohsiung, Pingtung, Taitung, Hualien, Taitung, Chiayi, Yunlin and Taipei from January 1984 through June 1986. It was evident that the introduced parasitoid had already established in Taiwan and performed as an excellent biological control agent of the coconut leaf beetle. Survey data indicated that this

biological control project was a great success (Chen, 1992b).

An indigenous parasitic wasp, *Trichogramma ostrinae* (Pang & Chen) (Hymenoptera: Trichogrammatidae), has been used as a biological agent to control Asian corn borer , *Ostrinia furnacalis* (Guenée) (Lepidoptera: Pyralidae) , the most important insect pest of corn in Taiwan, since 1984. So far, it has been applied to a total of 200,000 hectares of corn resulting in a considerable success in terms of effect on direct control of the pest and significant reduction of the use of pesticides. The wasp was propagated to a large number with the eggs of rice moth, *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae), as substitute hosts. An egg card machine was developed to improve the efficiency of producing cards stuck with eggs of the rice moth harbored by the wasp. Production of the egg cards with this machine is 10 times faster than that by laborers. It saves 2,626 hours and 4,700 US dollars in every lot of 3,000,000 egg cards (3.5 x 1.5 cm) that are used to release the parasitoid to 10,000 hectares of corn for controlling Asian corn borer (Chen, 1992a; COA, 1996). The improvement of technique for mass production will facilitate the application of the biocontrol method.

2. Green lacewing

Green lacewing, *Mallada basalis* (Walker) (Neuroptera: Chrysopidae), is an indigenous predatory natural enemy of several kinds of plant insect pests including spider mites, whiteflies, leafminers, thrips, and aphids. Successful control of those pests using the larvae of the green lacewing was achieved on citrus, muskmelon, papaya, jujube, and strawberry in screen houses and in the open fields as well. To improve the efficiency of mass rearing of the green lacewing, a prototypical machine with control of temperature, pressure and fluid level was developed to make microcapsulated artificial diets. The microcapsules about 396±48 μm in diameter and 10 μm in thickness were produced with 90% success rate. When *M. basalis* larvae were reared with the microcapsulated artificial diets modified from Hassan and Hagen's formula, 90% of individuals reached the adult stage in 20.7 days and the females deposited 348.5 eggs on average. The results were comparable with those reared with eggs of *Corcyra cephalonica* or *Aphis glycines* (Matsumura) (Hemiptera: Aphididae) (TARI, 1999). The improvement of rearing the predatory biocontrol agent will make its large-scale extension possible.

Another green lacewing, *Chrysopa boninensis* (Okamoto) (Neuroptera: Chrysopidae), is a polyphagous predator. Larvae are known to feed on a wide variety of small, soft-bodied insects such as aphids, scales insects, mealybugs, plant lices, spider mites, and on eggs and small larvae of a number of lepidopteran insects. *Chrysopa* was thus chosen as an agent for citrus red mite control. A preliminary experiment was conducted in a citrus grove. One thousand eggs of *Chrysopa* were released per tree. Twenty days later, the population density of citrus red mites in the released plot was much lower than in the control plot. The level of predation was sufficient to greatly reduce the mite population and keep it down to a very low level (TARI, 1999).

3. Flower bug

An indigenous predatory flower bug, *Orius strigicollis* (Poppius) (Hemiptera: Anthocoridae), had proved to be a good predator of small insects, such as thrips, and spider mites in Taiwan. Large number of *Orius* flower bug can be propagated under constant temperature and photoperiod conditions with bean [*Glycine max* (L.) Merill]sprouts as food and ovipositional substrate and flour moth, *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) eggs as prey. Field-release tests were conducted on eggplant and adzuki bean grown in open fields in central and southern Taiwan in 1998 and 1999 to evaluate the effect of *O. strigicollis* on biological control. In the biocontrol plots, densities of thrips gradually declined after the release of the flower bugs. The number of thrips in the chemical control plots dropped immediately after insecticide applications, but increased rapidly afterwards. Significant differences between biocontrol plots and chemical control areas appeared 4-6 weeks after the first release. The control effect lasted for several weeks. It has proved, that the flower bug, when released at the proper timing, is a strong natural enemy for the control of thrips on certain crops in open fields (TARI, 1999).

4.Predatory mites

Predatory mites, *Amblyseius fallacis* (Garman) (Arachnida: Phytoseiidae) and *Phytoseiulus persimilis* (Athias-Henriot) (Arachnida: Phytoseiidae), have long been regarded as promising biocontrol agents of plant spider mites. They were introduced from the USA and trials to evaluate their usefulness were carried out in three commercial strawberry fields for controlling two-spotted spider mite, *Tetranychus urticae* (Koch) (Arachnida: Tetranychidae), in Taiwan over three seasons during 1986-1989. Cooperating growers controlled diseases, mites and insect pests by means of a weekly or biweekly spray schedule before the fruiting stage. When the strawberry plants began to blossom, all chemical applications were stopped. *A. fallacis* and *P. persimilis* were released at a rate of 10/plant, at the time when two-spotted spider mite reached 2 active individuals/leaflet or infested 30% of sampled leaves. Satisfactory control of *T. urticae* was achieved when enough predatory mites were released and /or selective acaricides were applied as auxiliary control agents (Ho and Lo, 1992). The establishment of an integrated pest management system based on the biological control of *T. urticae* by both two predatory mites is in progress.

Both of the abovementioned predatory mites also gave effective control of Kanzawa spider mite, *Tetranychus kanzawai* (Kishida) (Arachnida: Tetranychidae), the most common spider mite on papaya. *P. persimilis* was more effective than *A. fallacis* when 500 predators/plant were released each time for two or three times in the test fields. The best releasing position on plant was found to be the lower leaves. The results showed that spider mite could not be found in the biological control plots. However, 41.4 mites and 469.0 mites/leaf were found in chemical control plot and untreated plot, respectively (Lo *et al.*, 1990). *A. fallacies* was also tested for its effectiveness of controlling Kanzawa

spider mites (*T. kanzawai*) on mulberry. A total of 5,271 million *A. fallacis* were mass produced, and released to 179.33 ha. of mulberry orchards. Encouraging results were obtained at Miaoli, Natou, and Chiayi. Moreover, *A. fallacies* has been found to be well established in pear trees and gave effective control of both species of spider mite. During the winter, the predatory mite migrated down into the ground cover, where it lived on broadleaf weeds and continued to prey on the two-spotted spider mite (Ho and Chen, 1992; Ho and Lo, 1992)

Use of sex pheromones

In order to enhance the application of non-pesticide method in the field, our government has financed the researches and extension of using sex pheromones for controlling the insect pests on many crops since 1983. The kinds being promoted included sex pheromones of tobacco cutworm, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae); beet army worm, *Spodoptera exigua* Hübner (Lepidoptera: Amphipyrinae); sweet potato weevil, *Cylas formicarius* (Fabricius) (Coleoptera: Brentidae); carambola fruit borer, *Eucosma notanthes* (Meyrick) (Lepidoptera: Tortricidae); smaller tea tortrix (*Adoxophyes* sp.); rice stem borer, *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae); tomato fruit worm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae); turnip moth, *Euxoa segetis* (Schiffermiller) (Lepidoptera: Noctuidae); Asian corn borer, *Ostrinia furnacalis* (Guenée) (Lepidoptera: Pyralidae) and cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae). Different kinds of sex pheromones were applied to crucifer, shallot, peanut, soybean, flowers, sweet potato, corn, carambola and tea, respectively.

In practice, they were used mainly to monitor or mass trap the target insect pests and occasionally to disrupt mating. Among them, the sex pheromone of sweet potato weevil has been most extensively applied in the fields. A funnel-shaped bottle suitable for trapping sweet potato weevil was invented and patented. The traps containing the sex pheromone lure were set in the fields at the rate of 40/ha. and the density of the weevil was reduced by 55~65% (Hwang and Hung,1991). This method has been applied to a total of 12,000 ha. of sweet potato since 1991. Besides, The sex pheromones of carambola fruit borer, Z-8-dodecenyl acetate and Z-8-dodecenol, had also been intensively studied. When they were used for mass trapping (40-50 traps/ha. lasting for 5 months), the density of the fruit borer was reduced by 75~89% as compared to untreated orchards. Assessment of using sex pheromone for mating disruption of carambola fruit borer was studied in the cage and orchards of small acreage. Data displayed that when the ratio of pheromones were properly formulated and the amount used were sufficient (53.28 g/ha), the mating inhibition in the orchards reached 97.45%. The fruit damage was reduced by 71% as compared to conventional chemical control (Hung and Hwang, 1993). The information pertaining to sex pheromones and attractants of insect pests is summarized in Table 2.

Other non-pesticide methods

Male annihilation by using materials other than pheromones has also been extended in Taiwan. Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), has always been a serious problem on several kinds of fruits. Different approaches to controlling Oriental fruit fly had been compared and using sugarcane-fiber plate absorbed with methyl eugenol (95%) and Naled (5%) for male annihilation was found to be the most effective and convenient method (Liu, 1992). Subsidized by the government, this method has been applied to about 580,000 ha. of orchards and groves since 1998. Melon-fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), has long been the key pest of cucurbits. Cuelure〔4-(p-acetoxyphenyl-2-butanone)〕mixed with insecticides has been recommended for male annihilation and commonly adopted by the farmers (Chen and Chang, 1993). Yellow sticky cards are commonly employed by farmers to trap small insect pests such as white flies, thrips, leafhoppers and aphids for monitoring and/or control purposes (Wang and Lin, 1992).

Pathogenic microbes including bacteria, viruses, and nematodes are regarded as promising biocontrol agents of insect pests. However, *Bacillus thuringiensis* Berliner has been the only microbe commonly used in Taiwan so far. It was first officially recommended to control diamond-back moth and then Asian corn borer (Hsiao, 1984.) Further studies showed that when mixed with fried rice bran, its efficacy of controlling Asian corn borer was significantly improved (Wu and Tseng, 1997).

Non-Pesticide Control of Plant Diseases

Physical control

1. Mulching and screen housing

There are two physical methods that are commonly used in Taiwan to prevent weeds, diseases or insect pests. For planting papaya, seedlings free from *Papaya ringspot virus* (PRSV), the limiting factor of papaya production in Taiwan, are planted in screen houses that prevent aphids, the transmission vectors of PRSV, from entering. The soil is covered with plastic sheets that prevent the growing of weeds. By this way, papaya has been stably produced at about 138,600 tons per year since early 1990's (Wang and Wang, 1995). Mulching of soil with plastic sheets is also commonly adopted by the growers to cultivate many kinds of crops such as watermelon, muskmelon, cucumber, tomato, eggplant, pepper, strawberry, etc. By this way, weeds are mostly inhibited and the occurrence of insect pests and soil-borne diseases are also reduced to some extent. Besides, the simple facilities, tunnels constructed with transparent plastic sheets under which muskmelon is planted, are also commonly adopted by the growers. By this way, viral diseases, downy mildew and some insect pests are effectively controlled (Huang *et al.*, 1999)

2. Steam sterilization

Recently, plant disease control by steam sterilization was used in planting high-value horticultural crops in Taiwan. Soils and cultural composts contaminated with plant pathogens were sterilized by the injection of steam (60-80℃ for 30 min). Plant diseases, such as lily yellowing disease caused by *Fusarium oxysporum* Shlechtend: Fr. emend f. sp. *lilii* Imle, *Thanatephorus cucumeris* (Frank) Donk, bacterial wilt of lisianthus caused by *Ralstonia solanacearum* Yabuuchi *et al.*, southern blight of ornamentals caused by *Athelia rolfsii* (Curzi) Tu & Kimbrough, etc., were controlled significantly by steam sterilization. In addition to the disease control, the quality of ornamental products and weeds control were also improved. Some horticulture growers, such as those who plant lisianthus and potted flowers, by the assistance of plant pathologists, developed their own steam pipe systems to improve the efficiency of operation in fields and screen houses (Lee, 1997). Although this method is labor-costly and time-consuming and therefore did not appeal to some growers, the benefits of reducing both the use of pesticides and adverse impacts on the environment still make it promising in the future, especially in the ornamental industry.

Use of pathogen-free propagating materials

Since seeds and seedlings are the starting materials for the production of crops and might be the carriers of pathogens and pests, the use of healthy seeds and seedlings is one of the most important strategies for non-pesticide controlling methods in many countries. By using healthy seeds and seedlings, the crop productivity and quality can be increased and improved. In Taiwan, the system of healthy seeds and seedlings production was started from the propagation and extension programs for seeds of the staple crops such as rice and coarse grains such as corn, soybean, peanut, and etc. In 1959, the Seed Testing Laboratory (STL) was established for the inspection of fields for foundation, registered, and certified seeds production and laboratory testing of the quality including their purity, moisture content, germination rate and health. The acreage of fields, mainly paddy rice, inspected amounted to about 2,000 hectares annually over the years (Kao and Lee, 2001).

Subsequently, Other propagation and inspection systems of virus-free seedlings of other crops were taken effect. Among them, the systems for potato, strawberry and sweet potato were established in 1972, 1991 and 1998 respectively. In the systems, STL are engaged in all the inspections and testing, and TARI, Chiayi Agricultural Experiment Branch Institute, and Taiwan Seed Improvement and Propagation Station (TSIPS) are responsible for the supplies of foundation seeds of sweet potato, potato and strawberry respectively. The inspection systems of those three crops operated well and were successful in supplying high quality seeds and seedlings (Chang and Lee, 1991; Kao and Lee, 2001).

The production technique of virus-free seeds of asparagus bean had been

developed by TARI and worked in practice by TSIPS. The extension area of healthy seeds has amounted to 824 hectares since 1996 (Kao and Lee, 2001). With regard to passion fruit and bamboo, TARI and Tainan District Agricultural Improvement Station are responsible for, respectively, the inspection and maintenance of virus-free nuclear stock repositories founded to meet the needs of commercial nurseries. By estimate, 250,000 virus-free passion fruit seedlings have been released per year since 1989 (Chang, 1991), and 60,000 healthy bamboo seedlings free from *Cucumber mosaic virus* have been provided since 1992 (Cheng and Yeh, 2001). With regard to citrus, the system is carried out mainly by Chiayi Agricultural Experiment Institute with technical support from National Taiwan University. Pathogen-free budlings of citrus are provided by Chiayi Agricultural Experiment Institute to meet the needs of commercial nurseries. In recent years, over 20,000 pathogen-free budlings of citrus were produced annually (Su, 2001). In addition, Taiwan Banana Research Institute and Taiwan Sugar Company take charge of the propagation and indexing of healthy seedlings of banana and sugarcane in Taiwan. The amount of healthy banana seedlings, produced by tissue culturing, supplied was estimated to 39,000,000 during 1983-2002 (Hwang, 2001; Kao and Lee, 2001).

Furthermore, to comply with the "Guidelines for Inspection of Designated Plant Diseases and Pests on Anthurium Seedlings", a mandatory inspection to ensure that the propagating materials are free from quarantine nematodes and bacterial blight pathogen, *Xanthomonas campestris pv. Dieffenbachiae* Vauterin *et al.* has been implemented since September, 1990 and over 900,000 healthy seedlings have been certified so far (Chang and Lee, 1991; Kao and Lee, 2001). Besides, our government is in the process of establishing of voluntary seed and seedling certification systems to encourage the production of high quality and healthy seeds. The certification system for *Oncidium* orchid seedling has taken effect since 2002 and asparagus bean, green bamboo and *Phalaenopsis* orchid will be the following ones to be promulgated this year. In the future, many more crops will be included in the voluntary seed and seedling certification system when the techniques are available. It is expected that the implementation of the voluntary seed and seedling certification system will significantly enhance the quality of seeds and seedlings of related crops and subsequently promote the competitiveness of Taiwan's agriculture (Chang and Lee, 1991; Kao and Lee, 2001).

The follows are the detailed descriptions regarding some of the prominent cases that used pathogen-free propagating materials to control major diseases in Taiwan.

1. Application of tissue culture technology for controlling *Fusarium* wilt of banana

Fusarium wilt of Cavendish banana caused by *Fusarium oxysporum* Schlechtend: Fr. emend f. sp. *cubense* (E. F. smith) Snyder & Hansen race 4 has been the major constraint for banana production in Taiwan. Previously, the disease had destroyed the banana industries of many countries in Central

America despite many attempts to control the disease. Continued banana production in Taiwan in recent years to supply both local and the Japanese market was attributed to the successful development of tissue culture technology for controlling *Fusarium* wilt. There have been two major achievements based on tissue culture technology leading to the success of controlling *Fusarium* wilt. Firstly, the technology was employed for mass propagation of disease-free plantlets for commercial planting. During 1983-2002, the tissue culture program had produced a total of 39 million plantlets for planting over 19,493 ha. and effectively contained the spread of wilt pathogen via infected suckers traditionally used by farmers. Secondly, because propagation of banana by tissue culture has shown the potential of producing substantial genetic variability, a mass screening program to select tissue culture plants resistant to *Fusarium* wilt was taken. Two resistant varieties, Tai-Chiao No.1 and Tai-Chiao No.3, developed by this breeding program were released for controlling *Fusarium* wilt in 1992 and 2001, respectively. Another new, higher yielding, resistant variety, Formosana, selected most recently was released in 2002. It is estimated that planting Formosana to replace Giant Cavendish would have the potential to increase yield by over 50%, and thus boost banana production considerably (Hwang, 2001; Hwang and Su, 1998).

2. Production and extension on *Bamboo mosaic virus*-free clones/plants of green bamboo

Because green bamboo shoot is rich in nutrition and delicious, it has been considered an important vegetable especially during the summer. *Bamboo mosaic virus* is the most destructive disease affecting the cultivation of bamboo shoots. The percentage of infection on green bamboo based on visible symptoms was 80-98.8 in the major growing areas of green bamboo. Previous studies revealed that the disease was transmitted mainly by cultural practices via farming tools. The control for the disease by planting the virus-free clones was effective. Since 1989, eye-inspection and/or the ELISA methods were used for the indexing of the disease, and green bamboo virus-free mother plant fields were set up at Tainan DAIS Hsinhua Branch Station in 1990. A virus-free clones nursery was set up at Paiho, and has been indexed periodically once a month and the new clones were distributed to the bamboo farmers at their request. This nursery has produced 60,000 virus-free clones for farmers so far (Cheng and Yeh, 2001; Kao and Lee, 2001). The establishment of the pathogen-free seedling system has significantly improved the quality and ensured the stable production of green bamboo shoots. This system will also facilitate expanding the international markets of green bamboo shoots.

3. Production and application of virus-free seeds to control virus diseases of asparagus beans

Asparagus bean, *Vigna sesquipedalis* (L.) Fruwirth, is one of the important vegetables in Taiwan in hot and wet summer seasons. Among various kinds of diseases attacking asparagus bean, viral diseases are identified as major limiting factors for its production. *Cucumber mosaic virus* (CMV) and *Blackeye cowpea*

mosaic virus (BLCMV) were previously found as the two major viruses attacking asparagus bean in fields. Both viruses were found seed-borne and the infected seedlings could serve as primary inoculum for the consequent early epidemic as resulted form mechanical and aphid transmission. Investigation was directed to evaluate the effects of planting virus- free asparagus bean seeds in controlling the viral disease in fields. An asparagus bean cultivar "San-Tse-Chin-Pi" was selected for production of virus-free seeds in 1990. By rouging virus-infected plant after detection by ELISA using antisera against BLCMV and CMV, plants were cultivated in insect proof screen houses until seeds were harvested. The seeds were then served as foundation virus-free stock. A large-scale virus-free seed propagation system was subsequently developed in order to satisfy sufficiently the demand from the growers in Taiwan. In 1991-1992 we conducted four field trials to test the feasibility of using virus-free seeds to control viral diseases of asparagus bean. The result indicated that the application not only significantly delayed the virus epidemic but also increased the yield and quality of bean pods and eventually the profit earned by the growers. In the field experiments, as low as 30-72% of final virus incidences was recorded in the plots sowed with virus-free seeds while in the same time 100% of incidences were detected in the control plots planted with commercial seed lots (Chang, C. A. 2001). Since 1993, planting of virus-free seeds has been routinely taken as one of the key measures in the integrated pest control program of asparagus bean in various production areas. Because of the consistent and significant control effect the virus-free asparagus bean seeds, produced in this program, have become more and more popular in Taiwan with time. About 1,086 kg of virus-free asparagus bean seeds were produced and released to four different major asparagus bean producing counties in 2001 (Kao and Lee, 2001).

Use of antagonistic microorganisms

1.Control of plant diseases with antagonistic bacteria

Bacillus subtilis Cohn, a gram-positive endospore-forming bacterium ubiquitous in soil and many plant surfaces, has long been used as a beneficial microbial agent for the control of plant diseases. The fungicidal application of *B. subtilis* was one of the primed focuses of biopesticide product development during the past decade and attempt of commercialization development was increasing. In Taiwan, A *B. subtilis* isolate was recently commercialized by Kuan-Hwa Chemical Co.. The product has been registered for the control of powdery mildew of pea, whereas its potential market remains to be evaluated. In order to explore the usefulness of native bacilli resources, *Bacillus* spp. with broad spectrum of antagonistic activity against various phytopathogenic fungi and bacteria were selectively isolated from cultural substrate and soil samples collected from field. Among them, isolate BS1 of *B. subtilis* was found outstanding because of the superior antagonistic activity against *Rhizoctonia solani* Kűhn, *A. rolfsii* and *Xanthomonas campestris pv. mangiferaeindicae* Robbs *et al.*. Its mass production techniques were developed. As for the practical

uses, more than 30 crop species have been tested in greenhouse and/or field trials. Effective control of soil-borne and foliar diseases has been demonstrated, and significant growth promoting effect was generally observed. The efficacy of disease control apparently had certain connection to the production of iturin-like antibiotic. By spraying application of the liquid formulation at 500-1000 x dilution, effective control of foliar infection of tobacco by *Cercospora* sp. (tobacco white spot disease), and leaf and fruit infection of mango by *X. campestris pv. mangiferaeindicae* (bacterial spot of mango) were demonstrated by field trials. In cooperation with private enterprises, the commercialization of BS1 isolate is in progress (Tzeng et al., 2001). *Streptomyces* spp., being gram positive also, are found ubiquitous among various terrestrial and aquatic natural habitats. The members of Streptomyces mostly are known to be saprophytic, aerobic, exist commonly in soil, grow well in slightly alkaline environment, and adapt well in high temperature and drought conditions. As many *Streptomyces* spp. are known to produce important antibiotic secondary metabolites and hydrolytic enzymes, the wide and extensive industrial application has been well recognized. In Taiwan, a *Streptomyces saraceticus* Berger *et al.* isolate, SS31, was selected and was shown to be effective in knocking down root knot nematode population in soil primarily because of its chitinase producing characteristics. In a preliminary screening test, it was noted that the test isolate was strongly antagonistic against fairly wide spectrum soil-borne fungal pathogens—especially members of Oomycetes. When solid formulation of SS31 was added to a soil amendment consisting mainly spent forest mushroom compost, fish meal, crab shell powder, and rapeseed pomace, and amended into the soil, the mixture effectively controlled *Fusarium* wilt of lettuce, and *Fusarium* wilt of banana. By spraying application of the liquid formulation at 1000x dilution, effective control of *Phytophthora* diseases of papaya and citrus has been demonstrated. It was also found effective for the control of downy mildews on cucurbit, rose, grapevine, etc. In addition, the formulation was found useful as soil drenching agent for the control of soil-borne diseases. The drenching treatment of the liquid formulation at 100 to 300x in dilution significantly reduced damping-off of cucumber seedlings caused by *Pythium aphanidermatum* (Edson) Fitz. In cooperation with private enterprises, the commercialization of SS31 isolate is in progress (Tzeng *et al.*, 2001).

2. Control of plant diseases with antagonistic fungi

In Taiwan, *Trichoderma viride* Persoon:Fries and *Trichoderma koningii* Oudemans had been reported to be pathogenic to mushroom in 1967 and water chestnut in 1955, respectively. However, most of species/ strains of *Trichoderma* were found to be the effective microorganisms for suppression of the plant pathogenic fungi after 1980. During 1980-1990, antagonistic *Trichoderma* spp. were studied and the promising ones were selected, formulated and added into soils and found to be effective on the control of several plant diseases including *Rhizoctonia* diseases, *Sclerotinia* disease, *Pythium* damping-off and *Phytophthora* blight. Among them, *T. viride* T20, *T. knoningii* T12, *T. knoningii*

T12-R33-D25, and *Trichoderma harzianum* Rifai TVCN2 were tested in large-scale trials. The results showed that they could inhibit *Rhizoctonia* disease of chrysanthemum and adzuki-bean (Liu, 1991). Recently, it was found that *T. virens* strain R42 and *T. harzianum* T22, when added to the soils, could induce cucumber resistance to *Cucumber green mottle mosaic virus* and suppress the sudden death of melon caused by *Monosporascus* spp. Both of the biocontrol agents also promoted the seedling and root growth of the crops in greenhouse and field trials. In addition, two isolates, *T. harzianum* T2 and *T. virens* T3 that had been formulated as granules, were found to be effective on the control of dollar spot of turf grasses caused by *Sclerotinia homoeocarpa* Bennett, when the dose applied had reached 10^6 cfu/g soil dry weight (Lo, C. T. 2001). The techniques for the mass production of the antagonistic fungi have been exploited.

Use of soil amendments

Eight formulated soil amendments, S-H mixture, SF-21 mixture, L-T mixture, AR-3 mixture, CH-1 mixture, GS mixture, FBN-5A and CF-5 liquid, have been developed, mostly by plant pathologists at National Chung Hsing University, and used for the control of soil-borne plant pathogens in Taiwan. The ingredients of these compounds are mainly fertilizers and organic wastes. Among them, S-H mixture and L-T mixture have been commonly used and FBN-5A is ready for commercialization.

1. Control of Fungal Diseases with S-H mixture

S-H mixture, developed in 1983, has been commercialized in Taiwan for the control of soil-borne diseases. Amendment of soil with S-H mixture, significantly reduced the incidence of watermelon wilt caused by *Fusarium oxysporum* Schlechtend: Fr. emend Snyder & Hansen f. sp. *niveum* (E. F. Smith) Snyder & Hansen, radish yellows caused by *Fusarium oxysporum* Schlechtend: Fr. emend f. sp. *raphani* Kendric & Snyder, pea wilt caused by *Fusarium oxysporum* Schlechtend: Fr. emend f. sp. *pisi* (van Hall) Snyder & Hansen, *Fusarium* wilt of banana caused by *F. oxysporum* f. sp. *cubense*, clubroot of crucifers caused by *Plasmodiophora brassicae* Woronin, cucumber damping-off caused by *P. aphanidermatum*, southern blight of pepper caused by *A. rolfsii*, *Rhizoctonia* blight of bean caused by *R. solani* and bacterial wilt of tomato caused by *R. solanacearum*. The effective rate of application for The effective rate of application for S-H mixture varied with diseases and crops, ranging from 0.5 to 2% (w/w) of soil. In more than 5,000 ha. of field trials in a variety of vegetable crops, S-H mixture not only reduced disease incidence but also improved root health, plant growth and plant stands (Sun and Huang, 1983; Sun and Huang, 1985).

2. Control of *Rhizoctonia* damping-off with FBN-5A

Formulated in Taiwan, FBN-5A is a mixture of spent forest mushroom compost, fish meal, bone meal, blood wastes, lime and allyl alcohol which is

effective in controlling *R. solani* AG-4, *Sclerotinia sclerotiorum* (Lib.) de Bary and reduce the incidence of *F. oxysporum* f. sp. *raphani* and *Fusarium oxysporum* Schlechtend: Fr. emend f. sp. *lactucum*. FBN-5A at 1% also inhibits the seed germination of weeds such as purslane, black nightshade, etc. The control effect of FBN-5A is due to the ammonia released from chitin and blood meal that poison and weaken the mycelia. The microorganisms and some inhibitors exiting in the mixture also reduce the colonization on cabbage seedlings by *R. solani* AG-4. When FBN-5A was mixed with the commercial BVB No. 4 medium, composed of 30 % black peat, 10% sand, and 70% white Germany peat, at the rate of 0.1%, the treatment was very effective in controlling damping-off of cabbage caused by *R. solani* AG-4. It not only reduced the disease incidence, but also enhanced the growth of cabbage. The results were confirmed in a large-scale experiment in a commercial automatic environment-controlled greenhouse (Huang and Huang, 2000). This study suggests that the FBN-5A compound offers potential for commercial use as an organic amendment for the management of *Rhizoctonia* damping-off vegetable crops. In 2000, a patent was issued on the formula of FBN-5A, and is about to licensed to industry for further commercialization.

3. Control of plant parasitic nematodes with LT-M

In Taiwan, parasitic nematodes have been big problems on different kinds of crops. A mixture, Lively Tiller Mixture (LT-M) consisting of 40% crab shell powder, 40% castor pomace, 5% soybean powder, 10% marine algae powder and 5% molasses was formulated. When amended into soil, the mixture significantly inhibited *Meloidogyne incognita* Chitwood, *Tylenchlus semipenetrans* Cobb and *Pratylenchus coffeae* Filipjev & Schuurmans Stekhoven. It was able to increase the population of nematode-trapping fungi such as *Streptomyces saraceticus*. Among the ingredients, castor pomace and crab shell powder were toxic to the nematodes. Hatching of egg masses or dispersed eggs was inhibited by castor pomace. The amendment of marine algae powder made the roots of host plants repellent to juveniles of *M. incognita*, *T. semipenetrans*, *P. coffea* and *Paratylenchus curvitatus* van der Linde (Tsay, 1997; Tsay, 1998).

When applied at the rate of 2,000 kg/ha. to grape vines, LT-M significantly decreased the root-knot indices and disease indices by 47.5, 67.8 and 42.8, 69.5% at summer and winter harvest, respectively, as compared to untreated control. Besides, LT-M also increased weight of grape by 57, 76 grams per cluster and increased sugar content by 3, 5 Brix°at the two harvest seasons, respectively. Antinematodal effect was enhanced when LT-M was applied for 2 successive years. LT-M in soil of citrus groves also reduced the population of *T. semipenetrans* and *P. coffeae* by 94.1 and 63.6% respectively, as compared to the control. Application of LT-M again significantly controlled root-knot disease of African daisy (Tsay, 1997; Tsay, 1998).

Use of resistant rootstock

1. Resistance of bitter gourd-loofah grafts to *Fusarium oxysporum* f. sp. *momordicae*

The *Fusarium* wilt of bitter gourd caused by *Fusarium oxysporum* Schlechtend: Fr. emend f. sp. *momordicae* Sun & Huang is hard to control in the field (Lin *et al.*, 1996). The technique of cleft grafting to a loofah rootstock was developed and adopted in Taiwan.

F. oxysporum f. sp. *momordicae* can only attack bitter gourd and summer squash, but not other cucurbits that have the potential to be used as resistant rootstock for bitter gourd (Lin *et al.*, 1996). The grafting experiments showed that among the various cucurbit plants tested, only pumpkin, bottle gourd and loofah could be used as rootstock for successful grafting with bitter gourd. Loofah was found not only the best candidate as rootstock for having a highest survival rate in plastic houses and displaying vigorous growth in fields but also showed high resistance to the wilt pathogen even when inoculated by artificial root-pruning method. For three years of field cultivation, the combination of bitter gourd scion (variety of Known You New No.3) cleft grafted to loofah rootstock (a local line of L39) was the best one to have high bitter gourd yields which reached 61-108 mt./ha.. In contrast, the non-grafted bitter gourd or grafted seedlings by whip root grafting only gave a yield from none to 24 mt./ha. (Lin *et al.*, 1998). This method has been commonly adopted by the growers in Taiwan.

2. Control of soil-borne diseases of tomato by grafting on resistant eggplant rootstock

The planting area of tomatoes in Taiwan measures about 4,000 hectares with the cultivated season during autumn and winter. In recent years, in order to meet the need of the market, cultivation of tomato within protective facilities during summer time has become more and more prevalent in southern Taiwan. Under high temperature and humid conditions, soil-borne diseases such as bacterial wilt caused by *R. solanacearum*, root-knot nematode caused by *M. incognita* and *Fusarium* wilt caused by *Fusarium oxysporum* Schlechtend: Fr. emend f. sp. *lycopersici* (Sacc.) Snyder & Hansen took place and caused severe losses.

To eliminate the greatest limiting factor in the production of tomatoes, Tainan Agricultural Improvement Station and Asian Vegetable Research and Development Center (AVRDC) have cooperated to develop practical control measures since 1998, and have obtained some encouraging results. Currently, TA 6 is the main cultivated variety of tomatoes which is resistant to high temperature and *Tomato rugose yellowing virus* (TRYV), but very susceptible to root-knot nematode. With regard to the widespread and persistent characteristics of soil-borne diseases, the researchers focused on screening varieties of eggplants for compatible resistant rootstocks. They found that grafting of tomatoes on eggplant rootstocks, EG190, EG203 or EG219, could provide

resistance to nematodes, and increased the yield by 8% to 43.3%. The resistant eggplant rootstocks were grafted with Known-You 301 cultivar of tomato, which was susceptible to bacterial wilt, and bacterial wilt was significantly reduced as well (Chen et al., 2001).

Genetic engineering

In Taiwan, several measures have been adopted trying to control plant viral diseases. The measures include the application of integrated cultural practices to escape the transmission vectors, the utilization of artificially induced mild strains for cross protection (Wang et al., 1992; Wang et al., 1987) and the generation of transgenic plants resistant to specified viruses by genetic engineering. Among them, the studies on the control of *Papaya ringspot virus* (PRSV) by genetic engineering have reached the most remarkable achievement.

1.CP-transgenic papaya

PRSV is a major limiting factor for papaya (*Carica papaya* L.) production in tropical and subtropical areas throughout the world. Control measures that has been used to protect papaya plants from PRSV infection, including selection of planting time to avoid the peak of winged aphids, the use of silver mulch to prevent aphids from visiting seedlings, and conventional cross protection. None of these control methods provided a long period of effective protection against PRSV. The CP gene of a local mosaic type strain isolated from Taiwan, designed PRSV YK, has been sequenced, and transferred into papaya via *Agrobacterium*-mediated transformation by Dr. S. D. Yeh, at NCHU, and 45 putative transgenic lines were obtained. When the transgenic lines were challenged with PRSV YK by mechanical inoculation, they showed different levels of resistance ranging from delay of symptom development to complete immunity. After the evaluation of resistance under greenhouse conditions, four highly resistant transgenic papaya lines 16-0-1, 17-0-1, 17-0-5 and 18-2-4 were further evaluated under field conditions for their reactions to infection by PRSV and for fruit production. The data obtained from two round of field trials displayed that lines 16-0-1, 17-0-1, and 17-0-5 were highly resistant to PRSV. The total fruit yields in the second trials of each line harvested for six months showed a 3.0 to 3.2-fold increase, and the commercially valuable fruits a 54.3 to 56.7-fold increase (Yeh *et al.*, 1998). These results indicated that the CP transgenic papaya lines have a great potential for control of PRSV in Taiwan.

2.Control of PRSV by genetically-engineered mild strains

An attenuated strain, PRSV HA 5-1, that infects papaya without conspicuous symptoms was previously obtained by nitrous-acid induction from the severe parental Hawaii strain HA. It has been used successfully for control of PRSV by cross-protection on a large scale in Hawaii and Taiwan. However, strain-specific protection limits its application in Taiwan and other geographic areas (Yeh and Gonsalves, 1994; Yeh *et al.*, 1988). In order to analyze the genomic region responsible for the pathogenicity of PRSV, infectious *in vitro*

transcripts of both HA and HA5-1 were constructed and various virus hybrids between severe parental virus and its mild mutant were generated by recombination at the cDNA level. The genomic region responsible for the attenuation of HA5-1 was determined, analyzed and compared with parental severe strain HA. This genomic segment (nt606-3526) of HA 5-1 was transferred to and replaced the corresponding region of the infectious cDNA clone of Taiwan severe strain YK. The pathogenicity of the generated hybrid virus YKMF was demolished and induced symptoms similar to those caused by to HA5-1. The cross-protection effectiveness of YKMF was evaluated under green house condition. Over 80% of YKMF-protected papaya plants did not show symptom for 3 months after inoculation with different severe strains (Chen *et al.*, 2001). The result indicated that the attenuated strain YKMF provides much higher degree of cross-protection and is less strain-specific than HA5-1 and can potentially be used as a better protective strain than HA 5-1 to protect papaya from PRSV severe infection in Taiwan.

In another attempt to improve the cross protection effectiveness of HA 5-1 against heterologous strains, the CP gene of Taiwan type W-strain TW was amplified by RT-PCR and used to replace the CP gene of HA 5-1 at the cDNA level. The generated recombinant HA 5-1W also induced mild infections on papaya and cucurbits similar to that induced by HA 5-1. Under greenhouse conditions, results of cross protection tests indicated that HA 5-1W provides a better degree of protection against PRSV-W than HA 5-1 in *Citrullus lanatus* (Thunb.) Matsum & Nakai, and *Cucumis metuliferus* Naudin, respectively (You *et al.*, 2001). The results indicated that these recombinant mild strains could potentially be used to control the important PRSV-W strains in cucurbitaceous crops.

Conclusion

As the general public has become more concerned than before about environmental conservations, attention has been paid to the use of chemical pesticides especially the effect of their residue. Integrated pest management (IPM) has been regarded as an important approach to reduce the application of the agrochemicals, and non-pesticide control method is one of the principle components of the IPM. In recent years, development of non-pesticide measures has obtained some successful achievements those are now being adopted for agricultural production in various countries. To follow the global trend, our government has set the development and implementation of non-pesticide control an aim to safeguard our agriculture production and to protect our environment in the 21st century. As we have gained accession to the WTO in January, 2002, it is important for us to strengthen our competitiveness in agricultural production and international agricultural trade. The extensive application of IPM including non-pesticide-based crop protection methods will help reduce the consumption of chemical pesticides and produce safer

agricultural products appealing to consumers.

Being aware of the significance of non-pesticide control methods, Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ) has put great emphasis in supporting and coordinating research and extension projects in relation to this aspect since its establishment in 1998. Efforts have also been made to promote local awareness of non-pesticide control through demonstration and extension programs, and to educate farmers through training sessions and workshops. Some satisfactory research results were obtained and are ready for the application for patents for commercialization. To continue promoting non-pesticide control and bring it into practical application, some important issues still needs to be further addressed:

Firstly, how to integrate non-pesticide control methods into practical IPM models so that farmers are willing to adopt.

Secondly, how to formulate non-pesticide agents for commercial production so that they can be produced at low cost and applied without fast decline in efficacy over time.

Thirdly, What are the impacts to our ecosystem of the non-pesticide control methods especially that use introduced or genetically engineered agents.

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Table 1. The records of introduced natural enemies during 1971-1995 in Taiwan

Year	Natural enemy	Target of pests	Origin	Status [a]
1971	*Opius importatus*	Beanflies	Hawaii	F
1971	*Opius phaseli*	Beanflies	Hawaii	F
1973	*Apanteles vestalis*	Diamondback moth	Holland	F
1973	*Diadegma fenestralis*	Diamondback moth	Holland	F
1974	*Apanteles glomeratus*	Imported cabbage worm	Japan	E
1983	*Tetrastichus brontispae*	Coconut leaf beetle	Guam	S
1983	*Tamarixia radiata*	Citrus psylla	Reunion	S
1983	*Trissolcus basalis*	Green stingbug	Hawaii	E
1983	*Amblyseius californicus*	Two-spotted spider mite	Hawaii	E
1983	*Typhlodromus occidentalis*	Two-spotted spider mite	US	F
1984	*Trichogramma nubilale*	Asian corn borer	US	F
1985	*Amblyseius fallacis*	Two-spotted spider mite	US	S
1985	*Diadegma eucerophaga*	Diamondback moth	Indonesia	E
1987	*Cotesia erionotae*	Banana skipper	Hawaii	E
1987	*Ooencyrtus erionotae*	Banana skipper	Hawaii	E
1988	*Dacnusa sibirica*	American leafminer	Holland	F
1988	*Encarsia formosa*	Greenhouse whitefly	Holland	F
1988	*Trichogrammatoidea bactrae fumata*	Litchi fruit borer	Thailand	E
1988	*Curinus coeruleus*	Jumping plantlice	Hawaii	F
1989	*Typhlodromus occidentalis*	Two-spotted spider mite	US	-
1989	*Phytoseiulus persimilis*	Two-spotted spider mite	US	S
1990	*Phytoseiulus persimilis*	Two-spotted spider mite	Australia	S
1990	*Nephaspis annicola*	Spiraling whitefly	Hawaii	F
1990	*Nephaspis bicolor*	Spiraling whitefly	Hawaii	F
1993	*Macrocentrus grandii*	Asian corn borer	US	F
1995	*Encarsia haitiensis*	Spiraling whitefly	Hawaii	-
1995	*Encarsia guadelopupae*	Spiraling whitefly	Hawaii	-

[a] S stands for successful in control, F stands for failure in establishment, E stands for established, and – stands for status uncertain.

Table 2. The application of sex pheromones and attractants in Taiwan

Sex pheromones or attractants	Purposes	Extension (ha) [a]
Tobacco cutworm (*Spodoptera litura* Fabricius)	Monitoring Mass trapping: 6-8 traps / ha / month	22,000
Beet army worm (*Spodoptera exigua* Hubner)	Monitoring Mass trapping: 6-24 traps / ha / 1-2months	1,700
Tomato fruitworm (*Helicoverpa armigera* Hubner)	Monitoring Mass trapping: 6-24 traps / ha / 1-2months	350
Sweet potato weevil [*Cylas formicarius* (Fabricius)]	Monitoring Mass trapping : 40 traps / ha / 1-2months	2,800
Carambola fruit borer (*Eucosma notanthes* Meyrick)	Monitoring Mass trapping: 40~50 traps / ha / 5~8months Mating disruption: 120 spots/ 0.1 ha / 5 months	400
Smaller tea tortrix (*Adoxophyes* sp.)	Monitoring Mass trapping: 25~40 traps / ha / month	250
Tea tortrix (*Homona magnanima* Diakonoff)	Monitoring Mass trapping: 25~40 traps / ha / month	1,350
Asian corn borer (*Ostrinia furnacalis* Guenée)	Monitoring	—
Oriental fruit moth (*Grapholita molesta* Busck)	Monitoring	—
Litchi fruit moth (*Cryptophlebia ombrodelta* (Lower))	Monitoring	—
Methyl Eugenol (95%) and Naled (5%)mixture	Monitoring: 549 detection points Trapping and killing; 4~6 pic/ha/2 months	580,000
Cuelure (85%)	Monitoring: 162 detection points Trapping and killing: 4~6 pic/ha/2 months	Commonly used
Methyl Eugenol 95%, Cuelure 85% (1:1) and Naled 5% mixture	Monitoring: 36 detection points Mass trapping and killing: 4 pic/ha/2 months	1,550

[a] The numbers are the total acreages that the methods had been applied to under the subsidiary of the government from 1998 to 2001.

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Soil Fertility Management of Sustainable Agriculture in Chinese Taipei

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Abstract

Of the major fertility management practices for wet rice, N fertilization is the most important. Since the type of cultivar and the climate have a profound effect on crop productivity, recommendations of N rates for rice are based primarily on the variety, the region and the cropping season. Recommendations of P and K rates are based primarily on results of soil testing for available P and K in the soil. There has, however, been a significant decline in rice response to these nutrients, compared with the response observed in the past, and in consequence there has been an accumulation of available P in the soil. More research should be done on whether further applications at such high rates are really needed. It is much stressed to develop the "on-site" and quick soil diagnosis to regulate and recommend rational fertilization in vegetable fields. Particularly in intensive cropped vegetable production for envionmental conservation. Leaf diagnosis and soil testing present as a guide for economic fertilization of orchards. Thus, The extension work of nutrient diagnosis in fertilizer recommendation service by leaf analysis and soil test should be strengthened and made really available to farmers.

Introduction

Soil fertility is the ability of a soil to deliver to roots the nutrients needed for the optimum growth of a specified crop. This ability is strongly influenced by the inherent soil characters, the interaction of these characters with the environment, and the management practices to which the soil is subjected. Thus, the soil fertility factors affecting crop production are quite complex and the fertility management even more complicated, because of the diversity of soils. Soil pH, organic matter content and the nutrient content of the soil are important parameters related to soil fertility (Lian 1989) . Leaf diagnosis and soil testing are valuable methods of determining the nutrient status of a crop and the soil in which it is growing, as a guide to what fertilizer is required.

As in all tropical and subtropical countries with year-round warm temperatures and high annual rainfall, the soils of Taiwan are constantly subject to rapid chemical decomposition and leaching. The depletion of soil fertility on most Taiwan's cultivated land is aggravated by highly intensive land use, whereby two to three or more crops are grown and harvested within each year. Therefore, the use of fertilizer to supplement soil nutrients plays an important role in crop production.

In Taiwan, the area planted each year in rice, fruit crops and vegetables are 339, 900 ha, 224,400 ha and 203,900 ha, respectively, corresponds to 32.3%, 21.3 % and 19.4% of total cropland. (Taiwan Agriculture Yearbook 2000) (Table 1). The application of chemical fertilizers and organic manures together with cultural practices are the major fertility management practices conducted in these cultivated soils of Taiwan. In this paper, fertility management of rice, vegetables and orchards cropland soils in Taiwan was discussed.

Fertility Management of Rice Soils

Rice yields depend primarily on the nitrogen fertility of the soil. Since nitrogen is the element most deficient in soil, the management of nitrogen fertility of soil is of major importance. The response in terms of rice yield to N, P, K over time is shown in Table 2. Of all the nutrient elements added, the yield response to nitrogen is the highest, It is also interesting to note that this response has maintained up to the present, in spite of the repeated applications of fertilizer over many years, This is because losses of N from both soil-N and added-N are fairly large when fertilizer N is added to the soil, so that the net increase of N in the soil is small.

The decomposition and transformation of soil organic nitrogen into nitrogen available to plants is a biological process which is affected by weather, soil texture, the presence of clay minerals, soil management, the nature of the previous crop and other variables. The evaluation of available N in the soil is thus more difficult than that of available P and K.

Rice productivity differs greatly in different area of Taiwan, depending on cultivars, climatic conditions, cultural techniques and soils. Of these four factors, cultivar and climatic conditions are considered to be most influential on crop productivity. Thus, the recommendation of N rates for rice on various soils primarily base on the variety, the area and the cropping season. The general pattern of recommendations, shown in Table 3, is based on the results of many field experiments.

The response of rice to phosphate and potash is generally lower than the response to nitrogen. Average consumption of P_2O_5 and K_2O per crop has increased to 34.3 and 46.3 kg/ha, respectively (average per crop during 1966-1986, despite the falling response) . As shown in Table 2, the average yield response of rice soils

in Taiwan to P and K fertilizers in years is only 0.6-0.8 and 0.7-1.5%, respectively, compared to that in past years (1929-1942 and 1953-1955), which reached as high as 5.4-6.7 for P and 2.4-5.1% for K.

Tables 4 and 5 show recommended rates of P_2O_5 and K_2O for rice soils according to soil test value of available P and K. These recommendations are based on the field calibrations of soil test carried out by various organizations from 1962 to 1968, revised and summarized by Su (1975). Special attention is given to increasing the level of potash applications in areas where drainage is poor. These criteria for P and K recommendations need to be revised, in view of the fall in the response of rice to these fertilizers A revision has been made which gives lower levels of available P to define the various classes, as shown by the values in parentheses given in Table 4. Table 6 shows that after continuously applied P fertilizers, soil available P in soil is increased (1978-1981), compare to that in past years (1959-1967).

In practice, rice in Taiwan today rarely receives applications of organic manure or green manure, except sometimes if upland crops are grown in rice fields as part of a crop rotation sequence. Organic matter content does not decrease, and may even increase, if chemical fertilizers alone are applied to rice fields. This is clearly shown in Table 7, compared to soils with a high or low organic matter content in past years in Taiwan.

Rice yield has increased very much, as indicated in Fig 1 which shows the yields in different years during 1937-1965, 1966-1986 and 1986-2000. This increase has generally been attributed to improvements both in rice varieties, which is with a higher response to N applications, and in cultivation techniques, including more efficient use of fertilizer and better control of insect pests and diseases.

Soils are acid either because their parent materials were acid and low in basic cations or because these elements have been removed from the profile by leaching or by the repeated harvesting of crops. Soil acidification is intensified by the use of nitrogenous fertilizers and by acid deposition from polluted air (Huang 1994).

Table 8 show the distribution of soils pH in Taiwan (1978-1981), which are lower compared to past years (1959-1967). Recent survey data also revealed that, in some area, soil pH decline continuously, and organic matter content are higher than that of past years(1978-1981) (Table 9)(Gao *et al*. 2001). Liming to correct soil acidity is also very important. A reclamation program for acidic soils has been established to encourage farmers to apply liming materials to strongly acidic farmland. So far, the program covers 5,000 ha of acidic arable land which is now under of reclamation (cropland soil fertility improvement project 2003).

Fertility Management of Vegetable Fields Soil

The negative aspects of the overuse of fertilizers have long been a concern in many parts of Taiwan. The environmental risk of using too much fertilizer is probably highest in intensively cropped vegetable fields where multiple crops are grown each year. In Taiwan, the year-round warm temperatures make it possible to grow 6 – 10 crops of vegetables each year. Very large amounts of both organic and chemical fertilizer are usually applied in vegetable production. The accumulation of salts and the risk of groundwater pollution by nitrates resulting from this intensive production may be the highest among all cropping systems. Table 10 and Table 11 show that there are significantly higher soil pH, organic matter content and EC (electric conductivity ds/m) in vegetable fields compared to the nearby paddy fields, and large amount of soluble salts accumulated (available P, exchangeable K, Ca, Mg) are visible in vegetable field (the total number of samples measured was 147 within Tao- Yuan area 1999) (Wang *et al.*2000b) .

Soil salinization of vegetable fields cultivated in facilities present another problem caused by overuse of fertilizers. With limited leaching, excessive salts largely move upward along with the evaporation of water and accumulated in the surface soil, which then hindered the seed germination and crop growth (Table 10) (Wang *et al.* 2000b) .

Table 12 and Fig 2 demonstrated that there was a significant leaching of NO_3^- down into the 150 cm depth soil and the amount of NO_3^--N already exceeded the 10 ppm limit set for drinking water (Wang 1994 , Wang *et al.* 2001b).

Recently, the development of soil test and improvement for determing the residual nitrogen in vegetable fields was undertaking, a new and simple technique of "on site" diagnosis of N fertility and its rapid recommendations of N fertilizer on leafy vegetable fields has established ; To reduce the nitrate or nitrite risks on environment the quick test methods of soil available N are assessed for on-site diagnosis and rapid fertilizer recommendation are now available in leafy vegetable fields. In laboratory, the results of incubation leaching and chemical extraction methods indicate available N contents detected by chemical extraction of 10% KCl, hot KCl and hot water are all positively and significantly correlated with those by incubation leaching. Relative yield of non nitrogen treatment reached 100%, when N content detected by chemical extraction fell in the 100ppm, 150ppm and 20ppm(Wang *et al.* 2000a, 2001b). Moreover, In field and pot experiment, there is extremely significant and linear relationships between available N contents and electric conductivity (EC,1 : 5) , and can be discribed by the equations : $Y=252.08X+2.0063$ ($n=23$, $R^2=0.7643^{**}$, from pot experiments) , and $Y=250.39X+0.2584$ ($n=22$, $R^2=0.6363^{**}$, from field experiments) . Here, Y is EC value ; X is NO^-_3-N extracted by 10% KCl(Fig. 3 and Fig. 4). Based on the results

above, the on-site N diagnosis could well be implemented in leafy vegetable fields with facilities. It would be recommended to withhold N fertilizer when determined EC larger than 0.4 mS/cm (suggesting soil NO^-_3-N over 100 $mgkg^{-1}$), either in fields equipped with plastic house susceptible to salt affected problem due to high evaporation and without rainfall leaching, or poorly drained fields with salts accumulated. When EC values fall in the ranges of 0.4-0.3,0.3-0.2 and 0.2-0.1 mS/cm, the N fertilizer rate should reduce to 1/4,1/2 and 3/4 of conventional rate cited in "Crop Fertilization Handbook", respectively. As of EC less than 0.1 mS/cm, the N rate would be recommended as referred to Crop Fertilization Handbook. Suggested N rate by rapid diagnosis, however, should be adjusted and increased in fields of well drainage (N loss prone to infiltration) or low soil organic matter level (below 3.0%) (Table 13), as soil N dynamics profoundly influenced by soil moisture and soil organic matter level. Consequently, development of soil quick test can promoted not only rational use of fertilizer to reduce production cost but also contributed to environment conservation (Wang *et al.* 2002a, 2002b).

Fertility Management of Orchards Soil

Leaf analysis and soil test are presently considered best tools for the diagnosis of fruit crops nutrition and orchard soil fertility. Leaf analysis and soil tests could present a good guide for proper fertilizer rate and soil management to farmers. A center for soil test and plant analysis has been organized in the Agricultural Research Institute. Well-equipped with automatic analysis instruments, and a computerized information system, the center provides accurate interpretation of leaf analysis and soil tests, as well as fertilization recommendations to farmers. In addition, an integrated orchard database has been established to integrate the results of accumulated long-term field surveys and trials. Thus, valuable information concerning diagnosis of nutrient status and fertilizer recommendation in orchards, long-term transition of soil fertility, together with regional statistics for leaf nutrient content, soil fertility, and fertilizer rates is all available to researchers and farmers.

Soil properties related to fertility level, such as pH, organic matter content, and soil texture as well as conventional fertilizer rates were also taken into account in the diagnosis and recommendation process. The nutrient elements diagnosed are nitrogen, phosphorus, potassium, calcium, magnesium, boron, copper, iron, manganese, and zinc. Criteria for eight kinds of orchards, i.e. citrus, grape, pear, loquat, carambola, mango, wax apple, and custard apple were collected in the diagnosis program. Even for the same kind fruit tree, different criteria are applied for different varieties and different crops growing in different seasons.

The diagnosis criteria are mostly derived from long term field survey and trials conducted in Taiwan. Because of limited information about some fruit trees, their criteria are adopted from foreign references and calibrated by further survey

and experiments conducted in Taiwan. Table 14 and Table 15 lists the optimum nutrient status and sampling methods for nutrient diagnosis of various fruit trees in Taiwan (Wang *et al.* 2000b, Chen *et al.*2001).

Leaf analysis is considered a handy tool for nutritional diagnosis and fertilization recommendations for orchards. The nutrient concentrations in a representative leaf sample can reflect the nutritional status of an orchard. Soil test, on the other hand, is not as useful for this purpose. This is because fertilizers are usually unevenly applied in orchards. Furthermore, the root systems of fruit trees can be very deep, so it is not easy to sample the soil representatively for diagnosistic purposes. A further point is that the nutritional status of a tree is the overall performance of the management history of the orchard in which it is growing, so the relationship between the N, P and K status of the soil and the condition of the tree may have little significance (Chang *et al.* 1992).Therefore, nutritional diagnosis and fertilization recommendations for orchards are mainly based on leaf diagnosis. Around 30,307 soil and 18,876 plant samples were taken and analyzed by the Agricultural Research Institute during 1989 to 2002 (Fig. 5). Reports of the analysis and fertilization recommendations were sent directly to the grower.

Conclusion

1. Of the major fertility management practices for wet rice, N fertilization is the most important. Since the type of cultivar and the climate have a profound effect on crop productivity, recommendations of N rates for rice are based primarily on the variety, the region and the cropping season. Recommendations of P and K rates are based primarily on results of soil testing for available P and K in the soil. There has, however, been a significant decline in rice response to these nutrients, compared with the response observed in the past, and in consequence there has been an accumulation of available P in the soil. More research should be done on whether further applications at such high rates are really needed.
2. It is much stressed to develop the "on-site" and quick soil diagnosis to regulate and recommend rational fertilization in vegetable fields. Particularly in intensive cropped vegetable production for envionmental conservation.
3. Leaf diagnosis and soil testing present as a guide for economic fertilization of orchards. Thus, The extension work of nutrient diagnosis in fertilizer recommendation service by leaf analysis and soil test should be strengthened and made really available to farmers.

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Table 1. Distribution of planting area of various crops in Taiwan

Year	1945		1970		1990		2000	
Crops	1,000ha	% of total	1,000ha	% of total	1,000ha	% of total	1,000ha	% of total
Rice	502.0	55.6	776.1	46.9	454.3	41.8	339.9	32.3
Grain crops	11.3	1.3	30.2	1.8	81.8	7.5	72.1	6.9
Legumes	39.9	4.4	153.4	9.3	7.7	0.7	117.9	11.2
Root crops	137.4	15.2	253.5	15.3	13.0	1.2	11.3	1.1
Tea	34.3	3.8	34.4	2.1	24.3	2.2	19.7	1.9
Tobacco	3.6	0.4	11.1	0.7	7.6	0.7	4.1	0.4
Sugarcane	107.7	11.9	87.5	5.3	69.1	6.4	38.9	3.7
Vegetables	35.3	3.9	141.5	8.5	188.2	17.3	203.9	19.4
Fruit crops	18.1	2.0	119.9	7.2	222.8	20.5	224.4	21.3
Flowers	0	0.0	0	0.0	6.2	0.6	11.0	1.0
Others	13.8	1.5	48.4	2.9	10.6	1.1	8.6	0.8
Total	903.5	100.0	1,656.0	100.0	1,085.6	100.0	1,051.8	100.0

Source: Taiwan Agriculture Year book.

Table 2. Response in terms of rice yield to nitrogen, phosphorus, potassium since 1929

Period in which experiments were conducted	Cropping season	No. locations	Experimental plots			
			-N	-P	-K	Complete[z]
1929-1942[y]	1st	117	72.6	94.0	97.6	100 (3,923)
1929-1942	2nd	117	76.4	93.3	94.9	100 (3,373)
1953-1955[x]	1st	82	66.8	94.6	97.8	100 (3,859)
1953-1955	2nd	91	75.0	94.5	95.6	100 (3,471)
1982-1983[w]	1st	80	75.2	99.4	99.3	100 (6,423)
1982-1983	2nd	80	81.2	99.2	98.5	100 (5,510)

[z] Expressed as yield index, 100 being the yield of the complete (NPK) plot. The numerical value (kg/ha) of the yield in the complete plot is shown in parenthesis.
[y] Source : Chu 1961.
[x] Source : Tseng 1961.
[w] Source : Lin 1984, Lin 1985.

Table 3. Recommended rates of N for wet rice production in Taiwan

Variety	Region[z]	N rate (kg/ha)[y]	
		1st crop	2nd crop
Japonica (medium height)	CSE	120-150	100-130
	N	110-130	100-120
japonica in excessively well-drained soil	CSE	180-210	170-200
	N	150	140
Indica (dwarf)	CSE	150-180	125-160

[z] C, S, E and N signify central, southern, eastern and northern Taiwan, respectively.
[y] The N rate should be raised by 10-20% if the direct-seeding system is used, and should be increased by 20-40 kg/ha in calcareous soils.
Source: Su 1975.

Table 4. Recommended rates of phosphate for wet rice production in Taiwan

Available P (Bray No. 1)			P_2O_5 rate (kg/ha)	
rating	mg/kg		1st crop	2nd crop
Very low	0-4	(0-1.6)[z]	70-80	50-60
Low	5-10	(1.7-5.0)	60-70	40-50
Medium	11-20	(5.1-12)	40-60	20-40
High	21-50	(12.1-30)	20-40	0-30
Very high	>50	(>30)	0-30	0-20

[z] Revised in 1987.
Source: Crop Fertilization Handbook 1983, Su 1975.

Table 5. Recommended rates of potash for wet rice production in Taiwan

Available K (Mehlich's)		K_2O rate (kg/ha)[z]	
rating	mg/kg	1st crop	2nd crop
Very low	0-15	60-70	80-90
Low	16-30	50-60	60-80
Medium	31-50[y]	30-50	40-60
High	>50[y]	0-30	0-40

[z] Plus 30 kg K_2O/ha in the case of poorly drained soils.
[y] For sandston ppm.
Source: Su 197e/shale alluvial soils and latosolic soils in northern Taiwan, M:31-70 ppm; H: >705.

Table 6. Comparison of the percentage distribution of soil available P level in past years

Available P in soil (Bray NO. 1)		1959-1967[z] (%)	1978-1981[y] (%)
rating	mg/kg		
Very low	0-4	7	5
Low	5-10	30	11
Medium	11-20	32	22
High	>20	31	62

[z] Soil fertility survey; the total number of samples measured was 78,600. Source:Lin *et al.* 1967.

[y] Soil fertility capability classification survey; the total number of samples measured was 5,730.

Source:Lin 1981.

Table 7. Comparison of the percentage distribution of surface soil organic matter content in past years

Organic matter content in soil		1959-1967[z] (%)	1978-1981[y] (%)
rating	g/kg		
Very low	<10	14.0	6.7
Low	10-20	50.6	38.1
Medium	20-30	26.9	33.1
High	30-40	8.3	16.0
Very high	>40	-	6.1

[z] Soil fertility survey; the total number of samples measured was 78,600. Source:Lin *et al.* 1967.

[y] Soil fertility capability classification survey; the total number of samples measured was 5,730.

Source:Lin 1981.

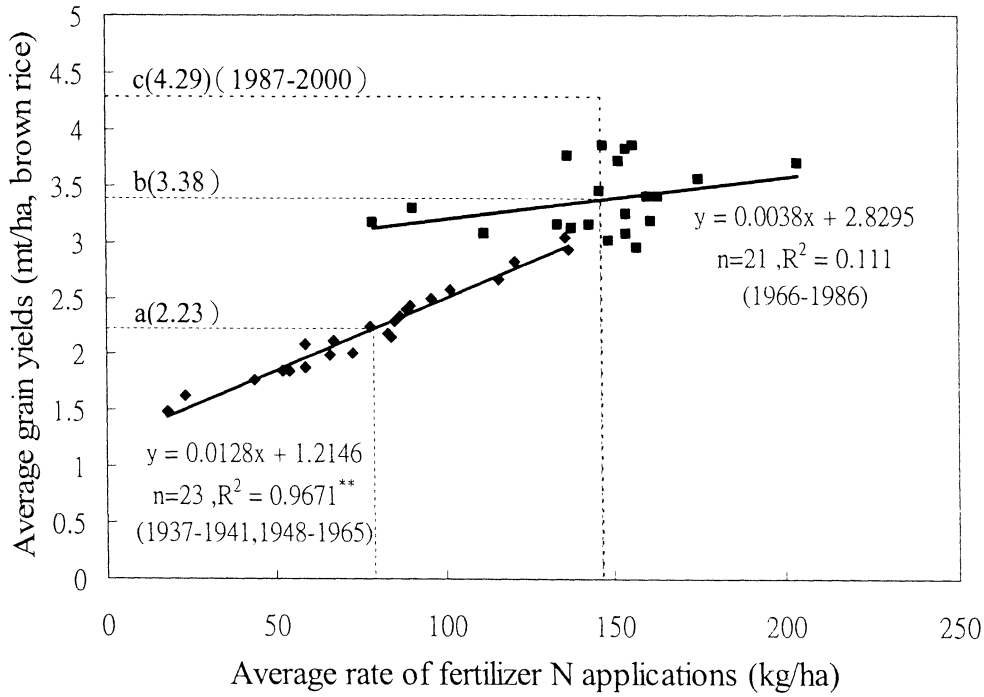

Fig.1. Relationship between average rice yields and rate of N applications over the period 1937-2000 in Taiwan.(Average of the 1st and 2nd crop, plotted from the statistical data of the Fertilizer Handbook 2003),(a,b,c: average rice yield of three stage respectively)

Table 8. Comparison of the percentage distribution of surface soil pH level in past years

Soil pH		1959-1967[z]	1978-1981[y]
rating	value	(%)	(%)
Strong acidic	<5.5	33.2	38.1
Acidic	5.5-6.5	25.2	23.9
Neutral	6.5-7.5	16.0	15.3
Alkali	7.5-8.5	22.3	22.0
Strong alkali	>8.5	3.4	0.7

[z] Soil fertility survey; the total number of samples measured was 78,600. Source: Lin *et al.* 1967.

[y] Soil fertility capability classification survey; the total number of samples measured was 5,730.

Source: Lin 1981.

Table 9. Comparison of surface soil pH and organic matter content of some villages in past and recent years

Location	pH		O.M.(g/kg)	
	1981	1994	1981	1994
Sin Chen	6.3±0.9[z)] (21)	6.4±1.0 (213)	25.2±9.3 (21)	26.0±11.7 (213)
Ji An	7.6±0.4 (21)	7.6±0.5 (494)	22.1±5.7 (21)	22.4±6.6 (494)
Chih Shang	6.5±0.6 (19)	5.7±1.0 (493)	28.9±6.3 (19)	33.9±10.4 (493)
Pei Na	6.5±0.9 (19)	5.3±1.1 (502)	28.9±8.2 (19)	26.4±8.8 (502)
Da Du	6.4±0.6 (8)	6.0±1.0 (220)	15.7±7.5 (8)	13.4±6.1 (220)
Yung Kang	5.3±0.6 (5)	6.5±1.1 (308)	11.0±4.2 (5)	16.1±5.6 (308)
Chang Hua	6.5±0.7 (20)	6.2±0.7 (469)	24.4±6.3 (20)	29.3±9.6 (469)
Ho Mei	6.5±0.6 (42)	5.9±0.8 (522)	20.6±5.4 (42)	26.6±14.0 (522)

[z] : means with standard deviation, the samples no. showed in parenthesis.
Source : Gao *et al.* 2001.

Table 10. Percentage distribution ratio of surface soil pH, organic matter content and EC in 147 vegetable fields (Tao Yuan,1999)

pH (1:1)		O.M.		EC (1:5)	
range	(%)	range g/kg	(%)	range dS/m	(%)
<5.0~4.5	10.9	<20	0	<0.5	33.3
<5.5~5.0	10.9	<30~20	15.7	<1~0.5	35.4
<6.0~5.5	15.7	<40~30	67.3	<1.5~1.0	13.6
<6.5~6.0	18.4	<50~40	13.6	<2.0~1.5	8.8
<7.0~6.5	12.3	<60~50	1.4	<2.5~2.0	5.4
≧7.0	29.3	≧60	2.0	≧2.5	3.4
Total	100		100		100

Source : Wang *et al.* 2000b.

Table 11. Percentage distribution of surface soil available P and exchangeable K, Ca and Mg content in 147 vegetable fields (Tao Yuan, 1999)

Bray NO.1 P		exch. K		exch. Ca		exch. Mg	
range mg/kg	(%)	range mg/kg	(%)	range cmol/kg	(%)	range cmol/kg	(%)
<100	2.0	<200	1.4	<10	21.1	<3.0	15.7
<200~100	8.2	<1000~200	53.1	<20~10	26.5	<6.0~3.0	34.0
<300~200	45.6	<1500~1000	27.2	<30~20	29.3	<9.0~6.0	36.7
<400~300	40.8	<2000~1500	11.6	<40~30	20.4	<12.0~9.0	12.9
≧400	3.4	≧2000	67	≧40	2.7	≧12.0	0.7
Total	100		100		100		100

Source : Wang *et al.* 2000b.

Table 12. Comparison of the NH_4^+-N and NO_3^--N concentrations in the water -saturated soil solution sampled at different soil depth either from a rice paddy or from a vegetable field (mg/kg)

Crops	Form of N		30 cm	50 cm	100 cm	150 cm
Rice	NH_4^+-N	Range	0.3-1.4	0.3-1.6	0.4-1.9	0.1-1.4
		Average	0.9 ± 0.5	0.7 ± 0.4	0.8 ± 0.4	0.6 ± 0.4
	NO_3^--N	Range	0.4-2.6	0.3-4.8	0.2-5.9	0.5-5.3
		Average	1.2 ± 0.8	2.1 ± 1.6	2.3 ± 1.1	1.7 ± 1.6
Vegetables	NH_4^+-N	Range	1.6-2.3	0.2-2.9	0.2-7.5	0.1-5.2
		Average	1.8 ± 0.3	1.5 ± 1.0	2.1 ± 1.8	1.9 ± 1.5
	NO_3^--N	Range	45-197	9-128	1.6-35	2.4-35
		Average	81 ± 65	39 ± 35	15 ± 13	14 ± 9

Source : Wang, Tan and Huang 1994.
Soil texture : Fine sandy loam.
Fertilization :
a)Rice paddy: chemical fertilizer N-P_2O_5-K_2O = 160-60-120 kg/ ha/crop ;
b)Vegetable field: chicken manure 1800kg/ha plus chemical fertilizer N-P_2O_5-K_2O = 750-350-540 kg/ ha/ 5 crop.

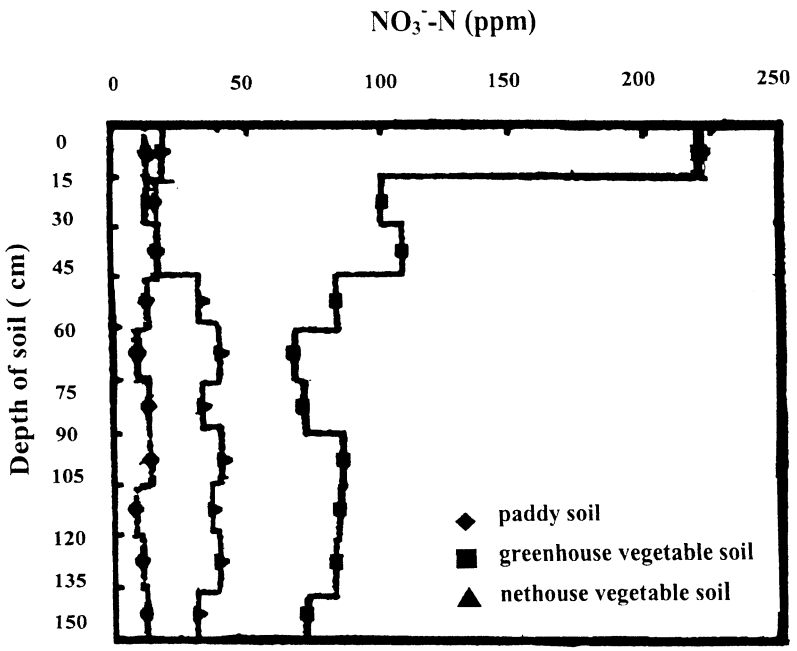

Fig.2. Level of nitrate-N in the profile of a vegetable soil compared with that in the nearby paddy soil , at the time of harvest (Hsilo 1995)
Source: Wang *et al.* 2001b.

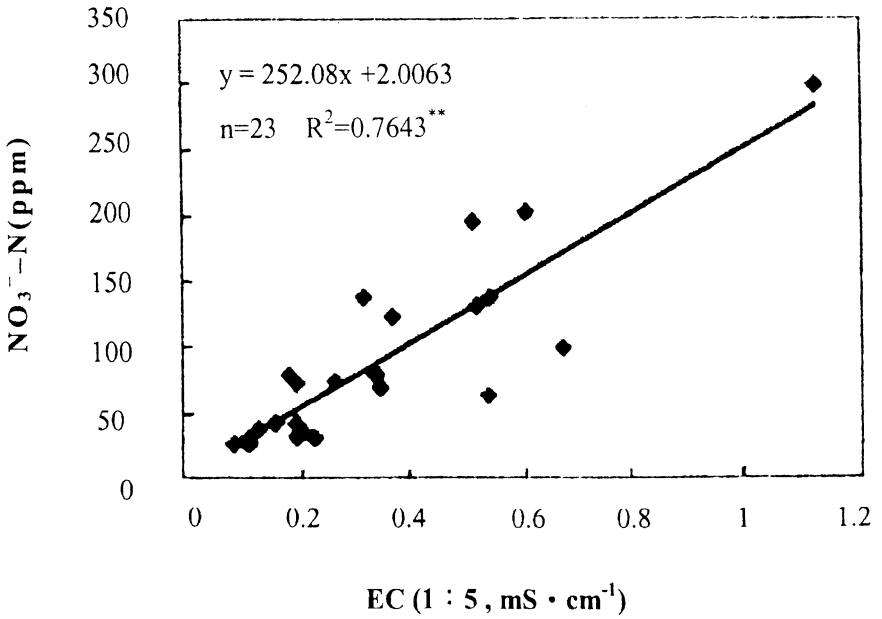

Fig.3. Relationship between EC value and NO_3^--N content in pot experiments
Source: Wang *et al.*2002a ,2002b.

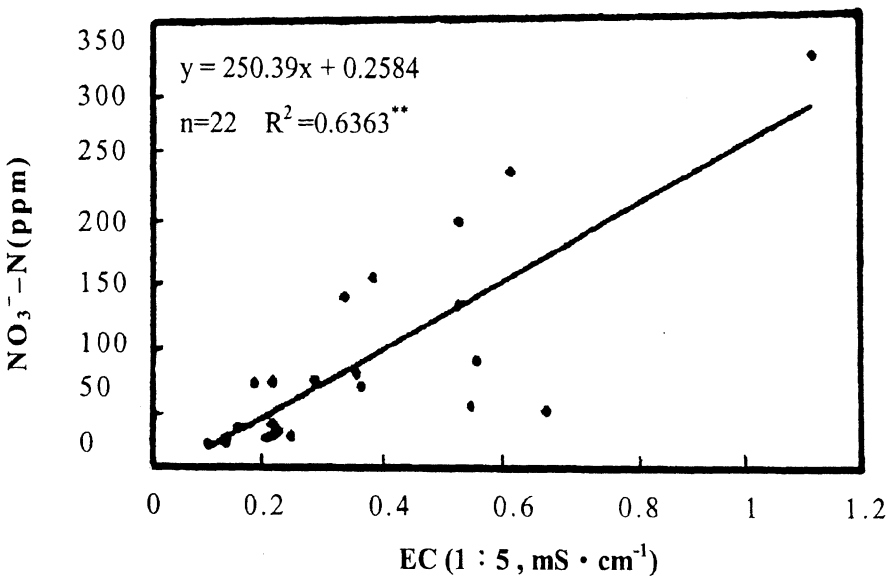

Fig.4. Relationship between EC value and NO_3^--N content in vegetable fields (Yungching 1998)
Source: Wang *et al.*2002a,2002b.

Table 13. Recommended rates of nitrogen in accordance with the EC value of leaf vegetable fields

EC (1:5)	NO_3^--N in surface soil		Recommended N. rates	
dS/m	mg/Kg	Kg/ha[y]	A[w]	B[x]
>0.4	>100[z]	>200	0/4 · R[v]	1/4 · R
0.4-0.3	100-75	200-150	1/4 · R	2/4 · R
0.3-0.2	75-50	150-100	2/4 · R	3/4 · R
0.2-0.1	50-25	100-50	3/4 · R	R
<0.1	<25	<50	R	R

[z] Derived from Fig.4.
[y] Calculated from NO_3^--N content multiple 2 million Kg surface soil per ha.
[w] In fields equiped with plastic house susceptible to salt affected problem, or poorly drained fields with salts accumulated.
[x] In fields with well drainage or lower organic matter content (below 3.0%) .
[v] R: Recommended N rate according to Crop Fertilization Handbook.
Source: Wang *et al.* 2002a , 2002b.

Table 14. Leaf diagnosis criteria for various fruit trees in Taiwan

Fruit tree	N	P	K	Ca	Mg	B	Ca	Fe	Mn	Zn
	----------%----------					----------ppm----------				
Citrus	3.0-3.2(Ponkan & Tunkan) 2.9-3.1(Liucheng & Other)	0.12-0.18	1.4-1.7	2.5-4.5	0.26-0.50	25-150	5-16	60-120	25-200	25-100
Grape	2.1-2.6(summer fruit) 2.4-2.8(winter fruit)	0.16-0.22	0.7-1.2 0.9-1.6	1.0-2.0 2.0-2.7	0.26-0.50	30-100	5-20	70-120	25-200	26-140
Pear	2.0-2.6	0.12-0.20	1.2-2.0	1.25-2.0	0.27-0.50	20-150	10-20	35-200	30-200	20-90
Loquat	2.0-2.5	0.12-0.20	1.0-1.8	0.8-1.5	0.18-0.30	—	—	—	—	—
Carambola	1.65-2.6	0.10-0.18	1.2-1.9	1.5-2.0	0.60-1.00	—	—	—	—	—
Mango	1.4-1.7	0.10-0.15	0.9-1.2	1.0-1.8	0.20-0.35	—	5-20	60-120	30-200	20-100
Wax apple	1.26-1.50	0.10-0.12	1.15-1.45	1.60-2.00	0.16-0.20	30-80	—	100-150	70-120	30-50
Custard apple	3.0-4.0(2nd crop) 2.4-3.2(1st crop)	0.18-0.22 0.10-0.14	1.4-2.0 0.5-1.0	0.2-0.7 0.7-1.0	0.34-0.86 0.35-0.55	— —	5-25 —	40-70 —	200-350 —	15-25 —

Source : Chen *et al.*2001, Wang *et al.*2000b.

Table 15.Suggested plant part and age, stage, position or condition to sample for various fruit tree in Taiwan

Fruit tree	plant part and age	stage	position or condition
Citrus	spring cycle leaves 5 to 6 months	during last August to early September	from nonfruit-bearing terminals
Grape (summer fruit)	30-40 days after bud germination	during March to April	from a fruit-bearing twig
(winter fruit)	22-28 days after bud germination	during August to September	
Pear	newly mature leaves	during March to April in plain or during April to May from sloped land	from short fruit-bearing twig
Loquat	mature leaves	during July to September (flower bud initiation stage), and the second is during January to February (middle stage of fruit development)	from fruit-bearing twig
Carambola	mature leaves	June	from nonfruit-bearing twig
Mango	newly mature leaves	during early February to early March	from the middle position of top twig (that has never bloomed and is in pre-flushing condition)
Wax apple	select the second and third newly mature leaves	during August to early September	from a fruit-bearing twig
Custard apple	the forth and fifth leaves	during early to middle December for 1st crop and from May to middle Jan for 2nd crop	from a nonfruit-bearing twig

Source : Chen *et al.* 2001,Wang *et al.*2000b.

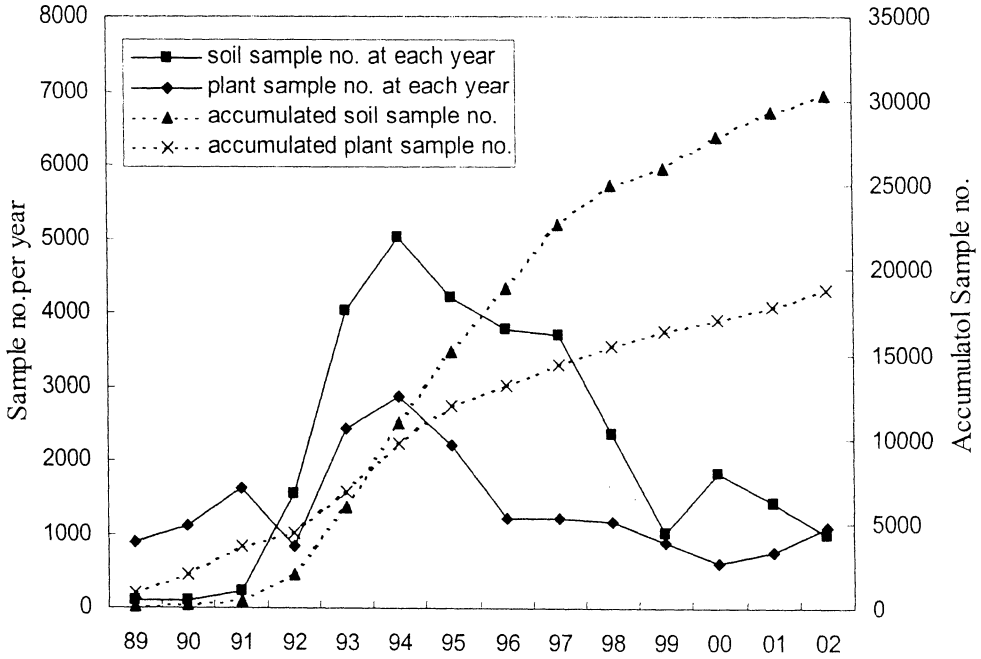

Fig.5. Annual and accumulated soil and plant sample number during 1989 to 2002

The 3rd APEC Workshop on Sustainable Agricultural Development
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Sustainable Rice production in Irrigated Central part of Thailand

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Sustainable Rice production in Irrigated Central part of Thailand

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Abstract

For the past 40 years rice production in central part of Thailand is low input technologies. Farmers use their wisdom knowledge for self-sufficient. The paddy field was submerged once a year that bring soil fertility. Farmers manage to grow many varieties of rice depend on land condition, that is in upper paddy they grown short duration varieties and in lower paddy they grown long duration varieties. This way of managing they can distribute labor properly, that labor may also do by sharing. Growing rice once a year, farmers in the central have no use of input such as, fertilizers, herbicides, etc. Although they got low yield less then 1 ton/ha, but sufficient for the well being of small farmers. In the past 30 years government had policy to increase the production of rice by irrigation project and also land consolidation, etc. The farmer growing rice 2-3 times a year. They put more fertilizers, herbicides and insecticides that increase production cost. Although they got high yield, high income but sometime could not cope with the increasing of production materials. Moreover from using high input most of the farmers also burning the rice straw to have time to grow move crops, that make soil degradation. Project set up to cope the problems. Concept of the project: 1. Participation of farmer or farmer group, 2. Integrated of all stake-holder, 3. Capacity building of all by research, 4. Improve of Agricultural resource, 5. Food safely for all. The Strategies: 1.Farmer is Center of development, 2.Farmer need approaches, 3.Integrated scientific knowledge and indigenous knowledge. As the result of the project, we have about 300 house holds, 4 farmer groups, 1 net–work join to work together. Integrated of all stakeholders, such as government, non-government organization etc. The farmers could reduce production cost by half, increase income and improved environment condition.

The 3rd APEC Workshop on Sustainable Agricultural Development
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Status of Greenhouse Insect Pest Biological Control in Korea

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Status of Greenhouse Insect Pest Biological Control in Korea

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Abstract

The greenhouse, a protected ecosystem for crop production, can be infested by a number of pests and their population can rapidly grow because of the ideal environmental conditions. These conditions are also well suited for many natural enemies that can be used in biological control programs. Korea has a large greenhouse areas (82,544 ha) and an insect pest population are also high compared with greenhouses in the western countries. In strawberries and tomatoes, pests are not much of concern since biological control can be easily employed using only several natural enemies. The biological control systems have been developed for insect pests of these crops in Korea through RDA. RDA has developed several mass rearing techniques including rearing of predatory mite, *Phytoseiulus persimilis*. This technique has been transferred and disseminated to Agricultural Extension Centers and three natural enemy companies. This year *Phytoseiulus persimilis* was used to control two-spotted spider mite on commercial strawberry planted in about 215 ha, banker plants for aphids control were used on commercial leaf vegetable planted in 34 ha, and *E. formosa* was used on tomato planted in 1 ha.

Key words: *Phytoseiulus persimilis. Encarsia formosa. Aphidius colemani.* biological control, greenhouse, vegetable

Introduction

The greenhouse environment represents an isolated ecosystem that can be conducive to outbreaks of arthropod pest populations. Pests can colonize greenhouses through the importation of infested plant and soil materials, migration via open vents and doorways, movement of plant and materials within the ecosystem, or survival during non-cropping periods. During crop production

inside greenhouses, mortality of pest species from density independent factors, such as moisture, wind, temperature extremes, etc., does not generally occur. Even though the greenhouse environment favors the build up of pest populations, it is also an ideal setting for successful biological control programs (Kaya and Parrella, 2001).

Spider mites, aphids, thrips, greenhouse whiteflies, and leaf miner are serious greenhouse insect pests in Korea (Kim et al., 2001). These pests damage a range of crops, especially strawberry, cucumber, pepper, tomato, and lettuce. Their population size can rapidly increase. To control these pests, farmers apply high levels of pesticides. Thus, too much pesticide has resulted in insecticide resistance and harmful residues which have been the recent concern of consumers. Consumers are aware of the harmful affects of pesticides on products and environment. Many countries are now trying to reduce pesticide usage. Biological control, therefore, is a viable alternative control method (Kim et al., 2001).

In Korea, biological control is used more often in strawberry than other crops because *P. persimilis* can control two-spotted spider mites under greenhouse conditions. Strawberry has the lowest pest and disease spectrum, and thus, systems for mass rearing of predatory mite were developed. Due to consumers' demand for chemical-free vegetables, biological control on commercial green vegetable crops including lettuce, started in 2001. The banker plants for *Aphidius colemani* were used for aphids control in these crops.

This paper describes the current situation of biological control of greenhouse insect pests in Korea.

Production of vegetable crops

An overview of the greenhouse area for major greenhouse crops in Korea is presented in Table 1. In 2002, watermelon has the biggest cultivation area followed by oriental melon, strawberry, cucumber, red pepper and tomato. Total greenhouse acreage for vegetables, fruits, and flowers were 82,544 ha, 3,426 ha, and 3,338 ha, respectively. The data represent the total area cultivated throughout the year. greenhouse area was 47,940 ha in 1999. Korean greenhouse acreage is larger compared with Netherlands (10,125ha), Italy (25,000 ha), and Spain (42,500 ha). Production cells (ton) per ha was 6.8 (cucumber), 5.6 (tomato), 3.4 (both oriental melon and red pepper), 3.3 (watermelon), and 2.6 (strawberry).

Table 1. Greenhouse vegetable production in Korea, 2002

Crops	Area (ha)	Production (t/ha)	Total Production (t)
Watermelon	19,740	3.5	692,099
Oriental melon	7,490	3.2	237,373
Strawberry	7,451	2.7	204,830
Cucumber	5,494	7.4	406,849
Red pepper	4,620	4.1	188,403
Tomato	3,353	6.5	218,485

Insect pests of greenhouse vegetable crops

There are 818 known species of vegetable insect pests in Korea (Choi, 199 0). However, less than 20 species are of major importance such as *Tetranychus u rticae*, *Myzus persicae, Trialeurodes vaporariorum, Frankliniella occidentalis*, a nd *Heliothis assulta* (Table 2). Strawberry and tomato have only a few pests whi ch are of major importance, but other crops have five problem pests. Thus, biolo gical control was focused in strawberry and tomato.

The cotton aphid (*Aphis gossypii*) is a key pest in watermelon, oriental melon, cucumber, and strawberry. Two-spotted spider mite (*T. urticae*) also attacks many kinds of crops including strawberry, melon and cucumber. Thus, the biological control against these mites and aphids were also given importance.

Insect pests populations start to increase from February to March or earlier in greenhouses with higher temperatures than open fields. The pest species in greenhouse crops depends on the host plants, temperature, and cropping system used. For biological agents to be effective and economical, it is best to apply them as soon as insect pests occur. Therefore, the monitoring of pest densities is very important in biological control.

Table 2. The pests of five important protected crops in Korea.

		Water-melon & oriental melon	Straw-berry	Cucumber	Red pepper	Tomato
Mites	*Tetranaychus urticae*	#	#	#	#	+
	T. kanzawai	+	+	+	+	¤
Aphids	*Myzus persicae*	*	*	*	#	+
	Aphis gossypii	#	#	#	+	¤
	Others	¤	+	¤	¤	+
Whiteflies	*Trialeurodes vaporariorum*	#	+	#	+	#
	Bemisia tabaci	¤	¤	¤	¤	+
Thrips	*Frankliniella occidentalis*	#	+	+	#	+
	Thrips palmi	+	¤	#	¤	¤
	F. intonsa	+	+	¤	#	¤
Leaf miners	*Liromyza bryoniae*	#	*	#	*	#
Others	*Heliothis assulta*	¤	¤	¤	#	¤
	Palpita indica	+	¤	+	¤	¤
	Spodoptera exigua	+	+	+	+	+
	S. litura	+	+	+	+	+

#: Pest of major importance, +: pest of minor importance, ¤: pest of negligible importance,

*: potential threat.

Production system and distributions of biological agents

Most countries using biological control have the ability to supply biological control agents either by commercialized production systems (Europe, USA, and Canada), governmental production systems (China), or self-production systems (Russia). Thus, an important research priority is the development of rearing techniques for natural enemies. RDA has initiated development of mass rearing systems for *P. persimilis, E. formosa, and A. colemani* and has began to transfer this technology to private companies and Agricultural Extension Centers. Now, these organizations are working mainly on the production and utilization of biological control agents.

Recently, demand for biological control of pests is rapidly increasing due to the need to limit pesticide application. This change has resulted from the social demand for food safety and environment conservation, increase in labor cost in

pesticide sprays, concerns about the health of growers, and increase in insect pollinator utilization. The government guarantees safe agricultural and animal products that do not use any chemical materials like agricultural chemicals, chemical fertilizer, and fodder additive, or use them below the optimum level. The non-chemical products are sold at a higher price than common products. Farmers who previously culture products using native materials which are less effective to insect pests now prefers to use natural enemies. Strawberry and leaf vegetable growers also prefer using natural enemies to control pests to avoid pesticide residues.

In 2001 and 2003, *P. persimilis* was used to control two spotted spider mite in 100 and 215 ha of strawberry greenhouse (Table 3). Other natural enemies were used only on small areas due to incomplete rearing systems.

Table 3. Greenhouse (ha) released with natural enemies.

Natural enemies	Target pests	Crops used	Area (ha) used			
			1998	1999	2001	2003
Phytoseiulus persimilis	Two-spotted mite	Strawberry	3	10.0	100.0	215.0
Aphidius colemani	Aphid	Leaf vegetables		0.1	3.3	34
Encarsia formosa	Greenhouse whitefly	Tomato		0.1	0.6	1
Orius stigicollis	Thrips	Red pepper		0.1	0.1	0.1

Control effects

Two-spotted spider mite in strawberry

Strawberry is one of the most popular fruit vegetables during the winter and spring seasons, with the total production ranking 7th in the world. However, strawberries are also affected by one major insect pest. The two-spotted spider mite (TSSM), *T. uricae*, is a major insect pest that is extremely difficult to manage on strawberries. This problem is primarily due to excessive use of pesticides, which kill not only TSSM but also the bees that pollinate the strawberries. Pesticide use has resulted in the development of highly resistant strains of TSSM. In addition, chemical control of TSSM on strawberries has become highly restricted in Korea because of increasing social concerns about pesticide residues on fresh fruits. Fortunately, the predatory mite, *P. persimilis* is now available for control of TSSM on strawberry inside greenhouses.

Strawberries are usually harvested in February and May, but recently, several strawberry growers in Korea began to harvest from December to May to command a higher price. Harvesting the strawberry fruits early would mean maintaining strawberries under high temperature without cooling. This condition leads to early development of two-spotted mites than normal cultivation.

Strawberries are cultivated in greenhouses, where temperatures are kept at ℃ from October to April. This temperature condition is preferred for the reproduction and dispersal of P. *persimilis*. The rate at which P. *persimilis* develops is a function of temperature and is described by a straight line over the range of temperatures between 15 to 30 ℃.

Port and Scopes (1981) showed that small numbers of predacious mite could control TSSM on strawberries in walk-in plastic tunnels in southern England, providing that the overwintering populations of TSSM were reduced by introducing predators in the autumn. Cross (1984) showed that introductions of predatory mites in March or early April at a rate of one mite per plant were consistently successful.

Greenhouse whitefly in tomato

In Korea, the greenhouse whitefly (GWF, *Trialeurodes vaporariorum*) was first found in 1977 on imported crops such as *Stevia*, lavender, and other medicinal herbs in Suwon. As the acreage of greenhouse crops increased since the late 1980s, damage and occurrence of GWF have increased. GWF has become one of the most serious pests on greenhouse crops such as tomato, cherry tomato, and cucumber.

Encarsia formosa is a parasitoid of the greenhouse whitefly that has been used as a biological control agent since the 1930s in Europe, and it is one of the most commercialized biological control agents used in more than 20 countries at present. *Encarsia formosa* was first imported by Korea in 1993 from the Netherlands when greenhouse whitefly started to cause problems in greenhouse tomato and cucumber.

After *E. formosa* was introduced, many experiments have been conducted to evaluate the control effect of this agent in experimental plots or farmer's greenhouses. Temperature turned out to be a limitation to the effectiveness of *E. formosa* because the minimum temperature of greenhouses during winter season is maintained below 10℃. Such temperature level can cause severe retardation of *E. formosa* emergence.

Removing lower leaves from tomato plants was too fast for newly parasitized mummy in the lower leaves to emerge. The grower insisted on

defoliating lower leaves to eliminate diseased leaf and for better quality of cherry tomato. In this case, the seasonal inoculative release method would not be effective and another implementation method should be developed to compromise with cultural practice. Van Lenteren et al. (1996) suggested keeping the defoliated leaves containing the mummies on the ground for parasite emergence.

Aphids in vegetables

Aphids are one of the most problematic insect pests of greenhouse crops because aphids can quickly develop to high population densities and develop resistance to insecticides in a short period of time. In particular, *Aphis gossypii* and *Myzus persicae*, polyphagous species with a worldwide distribution, are the most prevalent aphids species in Korean greenhouses. These species cause reduce yield and quality of crops and they can transmit virus, as well.

Aphids have been controlled largely through broad-spectrum insecticides, which can inhibit application of biological control agents of other insect pests. In order to avoid this harmful effect of insecticides, natural enemies with host specificity should be employed to control the aphids as well as implement IPM programs.

The endoparasitoid *Aphidius colemani* and the predatory gall midge *Aphidoletes aphidimyza* have already been commercialized in many countries because of their effectiveness against aphids on greenhouse crops. *Aphidius colemani* attracts much attention because it has 41 aphid host species (Stary, 1975). *Aphidoletes aphidimyza*, an aphidophagous species of Cecidomyiidae, is widely distributed over the world, and is highly effective against aphids, particularly in glasshouse (Meadow *et al.*, 1985).

The application of banker plants for introduction of *A. colemani* showed effective and economic biological control of aphids in watermelon and cucumber. Thus, the introduction of banker plants carrying the parasitoid before the incidence of the aphid should be useful aids in protecting the plants. Further work is necessary to improve control efficacy with small numbers of *A. colemani*. Improvement on the longevity and productivity of *A. colemani* on the banker plant is another subject to resolve. Inundative release of *A. colemani* was also effective to control aphids in greenhouses. However, direct comparison of the two methods was not made in this study.

Thrips on red pepper

Frankliniella occidentalis, Thrips palmi, and *T. tabaci* have become increasingly important agriculture pests of greenhouse crops in Korea. *Frankliniella occidentalis* and *T. palmi* which came from Southeast Asia has invaded agricultural crops in Korea in 1973. The occurrence of this pest has been widespread in greenhouses. To control thrips the indigenous *Orius* spp. and *Amblyseius barkeri* have been used since 1996. Another exotic species, *A. cucumeris* was also utilized in 1999 (Kim, et al. 1999).

The stored product insect pest, *Cadra cautella*, was selected as an alternative host in mass rearing predatory natural enemies. The rearing system of *C. cautella* was established using rice bran as a major dietary source. The rearing system is very convenient and efficient. With this system, about 645,000 eggs per day of *C. cautella* can be produced and around 45,000 minute pirate bugs can be reared with this production rate. The minute pirate bug, *Orius strigicollis*, will be used as a biological control agent against *F. occidentalis* in a greenhouse for red pepper.

Table 4. List of natural enemies commercialized in Korea, 2003

Natural enemies	Target pests
Aphidius colemani	Aphids
Aphidoletes aphidimyza	
Harmonia axyridis	
Phytoseiulus persimilis	Mites
Stethorus punctillum	
Encarsia formosa	Whitefly
Amblyseius cucumeris	Thrips
Orius strigicollis	
Diglyphus isaea	Leaf miner
Dacnusa sibirica	
Trichogramma evanescens	Moth and others
Steinernema carpocapsae	
Heterorhabditis sp.	

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The Agricultural sector in Malaysia

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The Agricultural sector in Malaysia

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Abstract

The Agricultural sector contributes 15-17% to the GNP valued at 15-18 billion RM per year. The major commodities are oil-palm (1,000,000 ha) with export value 5-6 billion RM, timber and timber product valued at 4-5 billion RM, animal products and fisheries with 2-3 billion, rubber with 1.0 billion RM and other minor fruit export like papaya, star-fruit, pineapple, mango, etc. The country still imports 11-12 billion RM of food products, and since local food production is 3-4 billion RM, there is a deficit of 7-8 billion RM. The Malaysian agricultural policy is to transform the agricultural sector into a modern, viable and competitive sector. Excluding the plantation sector, project implementation for the rural community will be under taken as an integrated basis (MOA approach) through agencies of the MOA like DOA, PORIM, RRIM, MARDI, DID, FAMA, PPK, RISDA and Fisheries/Veterinary Department. Malaysian agricultural policy makers will take cognizance of the importance of sustainable agriculture through conserving our agricultural resources and producing not only safe but also high quality agricultural products. To ensure that our products are safe we have implemented the Malaysia Accreditation scheme from January, 2002. This is based on EUREP-GAP and Cordeaux standard.

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Country policy profile for Papua New Guinea forwards sustainable agriculture development

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Country policy profile for Papua New Guinea forwards sustainable agriculture development

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Abstract

The agriculture sector remains the main stay of PNG' economy especially he we rural economy. While significant pockets of pure subsistence agriculture do exist, the livelihood of the majority of the rural population is supported by semi-subsistence agriculture which comprises traditional subsistence gardens that provide the basic needs for the family and small-scale commercial agriculture that provides the family with cash income. In terms of ts direct impacts at the livelihoods of the majority of Pupua New Guinea, semi-subsistence agriculture is the most important economic sector. It sustains the livelihood of the 85% of the population of the 5.1million people residing in rural areas and engaged in a mixture of cash cropping and subsistence agriculture. About 983,767 households are engaged in food/root crops and vegetables, livestock, fishing, coffee, coconut, coco oil and rubber. Agriculture contributes about 25% to the GDP and about 29% of the population is food consumers as based on the 1996/98 survey data which is increase of 3% over the period of 1990/92 period (FAO,2000) which classified PNG an a low income deficit by FAO 1996. Poverty and rural development are critical issues being identified for policy adjustment in addressing sustainable agriculture development in the country. Theses areas are clearly reflected in the governments MTDS 2003-2007 including expansion and diversification of the sectors, poverty alleviation and food security. Some problems that contribute towards effective implementation of the policies are; lack of constitutional policy capacity within the government system, inadequate linkage and integration with various stockholders, poor agriculture extensions service, marker, information, poor resources allocation, inadequate research capacity, poor and adequate skilled manpower, poor infrastructure and poor access to credit has hampered the progress of agriculture and rural development. Existing policies and strategies developed in addressing sustainable agriculture development include: Medium team Development Strategy 2003-2007

developed by the Department of National Planning and Rural Development (DNP & RD); 1996 Agriculture white paper, Draft rice policy 2003, National Agriculture Development Strategy 2002-2012, DAL Corporate Plan 1999, and the Draft Agriculture Development Policy 2003. Despite comprehensive work in policy formulation there has been limited action taken at the implementation of policies and strategies that would enhance agriculture, food security and rural development. The main line departments highly concerned by agriculture, food security and rural development are Department of Agriculture and Livestock (DAL), Department of Health (DOH), Department of National Planning and Rural Development (DNP & RD), Department of Education (DOE), Department of Environment and Conservation (DEC) and Department of Home Affairs (DHA) and the 19 Provincial Governments of PNG.. A better multi-stockholder coordination of rural development support activities at national, regional and local is required to identify gaps to promote and support sustainable agriculture development in PNG.

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Quality Management and Good Agricultural Practices

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Quality Management and Good Agricultural Practices

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Abstract

The peruvian agrarian vision is defined as following "Organized farmers, competitive, profitable, social, economic and environmental sustainable, in a democratic context with equality of opportunities", according to the official governmental documents. This objective revisit great importance because near 50% of the active population depends on the agrarian sector and because our country is privileged in resources and biodiversity. For this, is a social and economies imperative to work harder, hand to hand with the private enterprise, the civil sector and the international cooperation to achieve the objectives. Actually, the Minity of Agriculture is seriously commitment to improve its role: normative, orientator, promoter and regulator.

This is a great challenge for developing counties as Peru, characterized for the concentration of basic science and to be scarce and inefficient also, fragmented sector, great gaps between high and short farmer, low conscious to preserve our resources under the poverty jurisdiction.

This situation creates a vicious circle, reinforcing the poverty in the rural areas. In Peru, after a lot of experiences, we noticed that the unique way to assure the foods are enhancing farmer's capabilities in technical, management and organization aspects, so the farmers lead their doctrine, becoming in an active subjects of these process. In this sense, in the Ministry of Agriculture we proposed "Management Quality and Good Agricultural Practices-PromBPA". We adopted the EurePGAP Protocol as a strategy because its development proposal is integral: healthy for consumers, occupational safety in harmony with the environment. Also, is easy to understand for the farmers. We are conscious that it will be a long process, we face enormous internal and external obstacles, but we are convinced that we are in the right way.

The 3rd APEC Workshop on Sustainable Agricultural Development
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Sustainable agriculture development in the Philippines: revisit of tools and values of agriculture

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Sustainable agriculture development in the Philippines: revisit of tools and values of agriculture

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Abstract

In the Philippines, various forms of agricultural systems have emerged because of the pressures from rapid increase in population and accompanying urbanization. It was clarified that agriculture to be sustainable must take into account the role of the market and the overall economic development of the country, Agriculture development and technology applications must not be static and must continuously harmonize with the ever changing market and economic situations. The Philippines has passed a Law on Agricultural Modernization which protect agricultural lands from irrational conversion. Three good agricultural practices to address food security and water needs for agriculture were discussed. This includes the promotion of Hybrid Rice, the use of Organic based balance fertilization technology and the implementation of Community-base Rainwater Harvesting Technology. In order to provide a total picture of the role of sustainable agriculture and its contribution to national food security and environment, the concept of multi-functionality was presented. This method of valuation provide some estimate of the monetary values of the key externalities of agriculture.

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Sustainable Agriculture in New Russia

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Sustainable Agriculture in New Russia

Valery Popovtsev

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Abstract

The Russian agricultural privatization program was intended to run privately owned farms since 1991. Market-oriented economic reforms have accelerated in Russia. Today, on the transition period of Russia economic development the problematics of development of agricultural production and sustainable life-support connected to life and activity of the population of rural territories, seems urgent, very difficult and inconsistent. It's basic components include: Development of full market attitudes; The achievement of high level of efficiency in agricultural production of Russia ensuring food security; Formation of socio-economic conditions of life and activity of the rural population adequate to the modern requirements; Development of organic agriculture: Agricultural tourism; Landscape agriculture; Protection of natural resources and environment.

The 3rd APEC Workshop on Sustainable Agricultural Development

Issues Identified for Discussion at the 3rd Workshop for Sustainable Agriculture Development

The 3rd APEC Workshop on Sustainable Agricultural Development Issues Identified for Discussion at the 3rd Workshop for Sustainable Agriculture Development

Records show that sustainable agricultural practices have been implemented in crop production in many of the APEC economies for many decades. These practices resulted in profitable agriculture with the reduction of the use of synthetic chemicals including pesticides and fertilizers, and efficient usage of land and water resources through better education and extension programs. However, there is still room for improvement. In recognizing the divergent interests existed in agricultural production unique to each APEC member economy, the representatives of APEC economies attended the 3rd Workshop on Sustainable Agricultural Development held in Chinese Taipei on November 17-21, 2003, agreed that the concepts of sustainable agriculture should be promoted through the encouragement of establishing strategic alliance between the consumers and producers to ensure marketing of clean and safe products produced by environmentally friendly technologies. Such technologies, which have been practiced in member economies, should be collected, evaluated and then disseminated for wider adoption among the APEC economies through extension education and technical transfer programs.

To achieve the goals identified above, the action plans are proposed as follows:
Action 1.

Representatives of the member economies serve as advocates to promote sustainable agriculture concepts.

Action 2.

Commitments from the member economies are solicited to support the sustainable agriculture development through the initiation and continuation of appropriate programs to implement sustainable agricultural practices.

Action 3.

Representatives of the member economies are encouraged to develop an appropriate program to collect, evaluate and disseminate the sustainable agricultural practices, which have been used in each member economy.

Action 4.

Representatives of the member economies are encouraged to seek,

allocate or mobilize resources to support the activities to promote sustainable agricultural practices.

The 3rd APEC Workshop on Sustainable Agricultural Development

Summary Report

The 3rd APEC Workshop on Sustainable Agricultural Development

Agricultural Technical Cooperation Working Group
Sub Group on Sustainable Agriculture and Related Environmental Issues
Agricultural Research Institute, Council of Agriculture, Chinese Taipei
November 16 - 22, 2003

Summary Report

1. The third APEC workshop on sustainable agricultural development was held in Wufeng, Taichung, Chinese Taipei from 16 to 22 November 2003. Twenty-four participants attended the Workshop, including representatives from Australia; Brunei Darussalam, Canada; Chile; the People's Republic of China; Hong Kong, China; Indonesia; Japan; the Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; the Republic of the Philippines; Russia; Singapore; Chinese Taipei; Thailand; the United States and Viet Nam. The Participant List appeared in Annex 1.
2. The meeting has the following objectives:
   - To encourage cooperation among APEC member economies on developing sustainable crop production technology to promote sustainable agricultural development;
   - To gather information and share expertise and experience on conventional and innovative sustainable crop production technologies among APEC member economies; and
   - To formulate future joint activities for member economies to promote sustainable agriculture.
3. The workshop consisted of two parts, i.e., a three-day plenary session held during 17-19 November 2003. A two-day field trip during 20-21 November was arranged for the delegates to visit some agricultural production areas and research facilities in Chinese Taipei. The workshop provided a forum of plant breeding and cropping system, water management, soil fertility management and recycling of agricultural wastes, pest management, and education & extension in sustainable agriculture.

4. Opening Address was delivered by the host, Mr. Ming-Lai Wang (Chairman of Organizing Committee of the Workshop, Director General of International Cooperation Department, Council of Agriculture, Chinese Taipei). Welcome messages were delivered by Dr. Bin-Huei Chen on behalf of Dr. Chien-Yih Lin, Director General, Taiwan Agricultural Research Institute and Dr. Teh-Yeh Ku, Advisor, Food and Fertilizer Technology Center, Chinese Taipei.

Current Status and Future of Sustainable Agricultural Development
Dr. Kazutake Kyuma (Professor Emeritus, Kyoto University, *Japan*)

Sustainability is the prime requirement for agriculture, as it is an essential means for humankind to secure their food to survive. Until the dawn of the 20th century agriculture throughout the world had been basically sustainable. Animal-based mixed farming with crop rotational systems sustained the civilization of the western world. Thorough recycling of nutrient resources in rice-based crop production system in the East Asian countries was another example of sustainable agriculture. Even shifting cultivation was quite sustainable with a long natural fallow enough to replenish soil fertility. In this way agriculture did not disrupt the environment significantly and conformed to the order of the nature.

As crop yields increased, external inputs had to be introduced. Thus, besides manures some simple natural preparations like niter and guano began to be used in Europe already in the mid-19th century, but it was only after the middle of the 20th century, when a large amount of chemical fertilizers began to be used.

Introduction of powerful farm machinery in the turn of the 19th to 20th century was another momentum towards agricultural innovation in the United States. Draft animals lost their roles in a farm and fodder crops were eliminated from the crop rotation. Animal husbandry was separated from the farms specialized in food crop cultivation. Pursuit of efficiency and scale merits in the farm operation tended to force the farmers to take the path to monoculture. This tendency had become more and more prevalent in the latter half of the 20th century. All the agricultural technologies were mobilized to push up labor and land productivity in commercialized monoculture system. Ample use of chemical fertilizers and synthetic pesticides helped to suppress stresses caused by monoculture. Government farm policies and social as well

as economic facilities were also geared to encourage monoculture system to attain high productivity. Agriculture in the EU countries followed almost the same path in the years after the World War II.

In Japan, the farm size was much smaller as compared to the U.S. and EU countries, but the general direction of changes after 1950 was similar and as a result use of chemical preparations became excessive and recycling of organic wastes was almost totally abolished.

In many developing countries it had been increasingly obvious towards the end of the 20th century that the fallow period was shortened in the traditional shifting cultivation due to an increase in population pressure and legal controls imposed on the land use. In some cases shifting cultivation ceased to be the means of subsistence but became an operation for commercial crop production without an adequate means for nutrient replenishment, resulting in rapid deterioration of sustainability of the system.

All these changes that occurred in agriculture after 1950 have weakened intrinsic sustainability of agriculture and enhanced its negative impacts on the environment, such as soil erosion and degradation, water and soil pollution, and even health hazards to the people through the food and water. As such undesirable effects had become obvious, the people and the governments in developed countries gradually came to recognize the environmental hazards of the modern high-input agriculture.

In the U.S. and EU countries, the timing of recognition of the adverse effects induced by intensive agriculture coincided with that of the economic stress caused by the overproduction of cereals in the early 1980s. This became the opportunity to direct the public concerns to the restoration of sustainability in agriculture. The USDA's Program of Low Input Sustainable Agriculture (LISA) started in 1988 as an implementation of the 1985 Farm Bills. In EU (formerly EC), too, policies to encourage deliberate fallowing started in 1985, and later in 1990, regulations encouraging agricultural practices to conserve the environment and rural landscapes were enacted. Meanwhile, the Japanese Government officially announced its new agricultural policies in 1992 to promote the environment-conserving agriculture.

Under these programs in the developed countries a variety of agricultural practices, ranging from rigorous organic farming to alternative agriculture with low external input are being exercised. For the farmers practicing these environmentally sound farming a part of the reduction in their

incomes due to reduced outputs may be compensated by the premium price paid by the health-conscious consumers. However, the majority of farmers in these countries are still adhering to the conventional agricultural practices with, at best, a little reduced use of chemical fertilizers and pesticides.

In most developing countries, agriculture has not yet undergone very drastic changes from its traditional form, but an increased pressure of population and cash economy begins to force farmers to intensify their farming practices, often accompanying the use of modern external inputs. Thus there is a worry that agriculture in all these developing countries might eventually follow the same track of diminishing sustainability as already trod by that in the developed countries in their course of agricultural intensification. People should realize that agriculture is in the pivotal point that governs the life and the environment and nothing is more precious than safe food and clean water that can be secured by sustainable agriculture.

Panel Discussion

In the advent of commercialization and increasing merchant orientation of agricultural production, the farmers were to shift their production from sustenance (singly maintaining self sufficiency for their family) to producing food in excess of their need to contribute to national food security feeding the society at large.

In sustaining the increasing demand for surpluses from the farm, the farmers are encouraged to adopt technologies (chemicals, N fertilizers) that eventually contributed to land water degradation. The national government can ask the farmers to shoulder the resulting social cost related to environmental degradation. It is just fair that the society at large and the government handle this social cost or possibly return them to the farmers as incentives.

Involve agricultural specialist with environmental scientist/engineering for the development of environmental net work in Japan. This is possible to achieve sustainable agriculture and environmental protection quality.

Concerning the rotational cropping pattern and irrigation system, we need the modernized rotational irrigation system managed by government or by farmer themselves. Because this system affects the redistribution of water

resources, some disputes among regions or among farmers will surely happen. A specially committee or organization responsible for implementing this system and handling the disputes is necessary.

Most of contents of presentation are agreeable, in particular, the "Alternative Agriculture". However, what the role of government should play for realizing the goal of alternative agriculture? Unlikely, most of governments' financial capability would not be capable of supporting the alternative agriculture in full. If the realization of this goal leaves farmers to carryout, farmers would not follow the practices suggested, except the practice is profitable to them. Therefore, the economical viability would be key factor to dominate the success of alternative agriculture.

Session 2—Plant Breeding and Water Management

Dr. Chia-Yin Tsai -- "Strategy to Increase Maize Productivity While Reducing Nitrate Contamination to the Environment"

Plant nutrition, along with moisture, temperature, light intensity, and pest management interact with the genetic composition of hybrids to determine maize production. However, nutrient stress especially nitrogen deficiency most frequently limited vegetative growth and grain yield, not only N plays an important role in structural and metabolic functions, but also affects grain fill kinetics (Tsai et al., 1990). For maximum kernel development, the plant must either uptake most of required N during the stage of vegetative growth, or maintain absorbing inorganic N throughout the entire growing season. However, maize hybrids vary substantially in N nutrition during the growing season (Tsai et al., 1991) and also differ in yield potential.

Some in this presentation include: 1) effects of N sink on dry matter accumulation in maize kernels, 2) predictions of grain yield potential for maize hybrids based on the N sink capacity, 3) differences among maize hybrids in nitrogen uptake and utilization, and 4) genetic variations in the ability of maize inbreeds to utilize ammonium (NH_4^+) nutrition. A better understanding of above subjects should be helpful to come up with an efficient N management program and breeding strategy to increase grain yield while reducing nitrate ($N0_3^-$) contamination.

Q: Prediction of the amount of nitrogen fertilizer to apply, based on genetic or biochemical patterns of a cultivar, is very promising. So many papers on the related issue have been published in environmental engineering journals. Did anyone or could someone use your data to verify your prediction or make them practical? (Dr. P. Y. Yang)

A: This prediction is done over a period of 12 years. So I am quite sure that the prediction is still valid. Collaboration with other fields is extremely important. We often do only straight-line integration, but never super impose studies with other fields, such as mechanical engineer and computer science. Adapting their results into agriculture is very vital for the future of agriculture. (Dr. Chia-Yin Tsai)

Q: The so-called junk protein may be very important for corn. The essential amino acids are only essential for animals but not plants. Advantages of having zein protein for corn may not be the same for animals. (Dr. W. H. Ko)

A: Dr. Tsai: Corn plants would like to produce healthy kernels for survival. My studies indicated that zein protein is produced not just to serve as a reserve to facilitate germination. During germination, formation of the primary roots is induced after 26 hours of the germination. The mechanisms is to absorb exogenous nitrogen rather than relying on endogenous nitrogen. Starch, which could not be photosynthesized at the early stage of germination, needs to be provided for energy. Relative to nitrogen, roots can absorb it from the environment through the nitrogen fixation process. Zein protein is there because corn wants to make sure that once large quantity of zein is accumulated, the kernels can become bigger and healthier. (Dr. Chia-Yin Tsai)

Dr. Hai-Sheng Ko -- "Water management"

Uneven distribution of precipitation in space and time, together with lack of suitable dam sites have caused water utilization in Taiwan under unfavorable condition, regardless of its annual average precipitation being one of the highest in the World. The rotational cropping pattern and rotational irrigation were adopted to cope with limited water resources, as could be shared equally by more water users with precisely arranged water distribution schedule. In particular, during 1950s to1980s, these two practices had assisted the agriculture of Taiwan to fulfill its designated goal of producing adequate

food. This achievement might be attributed to the technical renovation on water management and investment in the improvement of irrigation facilities. These practices had enabled water controllers to better convince the water users that the scarcity of water is being distributed equally to a maximum extent even more than the technical amelioration and investment to of water management. Moreover, crop rotation with paddy rice, upland crops and sugarcane has extended the paddy area, deemed to be in favor of conserving ecosystem and enhancing biodiversity of environment. Recognizing the fact that the profit of irrigation is no longer able to balance the strict rotational cropping and irrigation, these two practices have gradually relaxed and modified nowadays. The Government agency concerns and is aware of this change and tries to pursuit the spirit of equity to allocate agricultural resources in a more sustainable way.

Q: Is this modernized rotational irrigation system applied in Taiwan maintained by the Government or by farmers? How to resolve the water resources sharing disputes among the regions or farmers? Is there a commission or organization responsible? (Dr. Youqi Chen)

A: For paddy rice, 85% irrigation area is maintained by 17 irrigation associations, which are autonomous farmers' organizations but fully supported by the government. About 20 years ago farmers had to pay 100% maintenance costs and 40-60% of the capital costs for improvement of the irrigation system. About 6 years ago, rice farming was not as competitive as used to be, the government suspended the authority of the irrigation associations for collecting the fees from farmers. Nowadays, 85% of the area maintained by the 17 irrigation associations is fully supported by the government. In Taiwan the irrigation associations are as large in scale as that in Japan. However, the large scale leads to strong political influence exerted by the irrigation associations. Maybe a smaller scale is probably better for political stability. (Dr. Hai-Sheng Ko)

Q: The precipitation utilization rate was quite low according to your presentation. This rate in the last 10 years varied from 22% to 14%. Why? (Dr. Kazutake Kyuma)

A: It is due to the uncertainty of the availability of water. As you can see precipitation was 20% higher than the average in some years. In addition, the uneven distribution of precipitation also contributed to the uncertainty. Most of the water discharged into to the sea. This kind of uncertainty caused the big

variation in water distribution in space and time. This resulted in disputes over water in the past. The irrigation systems helped resolve the disputes over water. (Dr. Hai-Sheng Ko)

Economy Report

Mr.Youqi Chen -- "Integrated Agri-disaster Management for Sustainable Agricultural Development in China"

For China, sufficient food with good quality and better life for in 1.6 billion people in 2003 will be of the highest priority for sustainable agricultural development in a short and medium term. To achieve those goals, new technologies for management and rational utilization of agricultural resources, are of great significance. Chinese agriculture under the regime of sustainable development is suffering from natural disasters such as drought, flood and forest fire, etc. very seriously. So how to combat the disasters and to decrease the economic loss with the help from new technologies such as remote-sensing and GIS (geographical information system) has attracted more attentions from governmental officers and scientific researchers. Under the supervision and practical demand for policy-making of Mainstay of Agriculture, the Institute of Natural Resources and Regional Planning, CAAS, P. R. China has developed an integrated agri-disaster monitoring and evaluation system, which is now operationally running with functions like disaster detecting, monitoring, forecasting, economic loss evaluating and providing scientific supporting. In has been proved that this system is very effective in sustainable agricultural development in China.

Q: Recently there were a number of locust outbreaks in China. Do you enlist it as major natural disaster in China? (Dr. T. Y. Ku)

A: Remote sensing, despite its high costs, is being set up to monitor locust movements in China. In addition, ground surveys are being conducted. (Dr. Yaoqi Chen)

Mr. Somporn Isaranurak -- "Sustainable Rice production in Irrigated Central part of Thailand"

For the past 40 years rice production in central part of Thailand is low input technologies. Farmers use their wisdom knowledge for self-sufficient.

The paddy field was submerged once a year that bring soil fertility. Farmers manage to grow many varieties of rice depend on land condition, that is in upper paddy they grown short duration varieties and in lower paddy they grown long duration varieties. This way of managing they can distribute labor properly, that labor may also do by sharing. Growing rice once a year, farmers in the central have no use of input such as, fertilizers, herbicides, etc. Although they got the yield less than 1 ton/ha, but was sufficient for the wellbeing of small farmers. In the past 30 years the government had policy to increase the production of rice by irrigation projects and land consolidation. Farmers grew rice 2-3 times a year. They put more fertilizers, herbicides and insecticides that increase the production costs. Although they got high yield and high income, they could not cope with the increase of the costs for production materials. In addition to high inputs, most of the farmers also burned rice straws to save time for growing move crops, resulting in soil degradation. Projects were set up to cope with the problems.

Mr. Teng Tay Yeo -- "The Agricultural sector in Malaysia"

The Agricultural sector contributes 15-17% to the GNP valued at 15-18 billion RM per year. The major commodities are oil-palm (1,000,000 ha) with export value 5-6 billion RM, timber and timber product valued at 4-5 billion RM, animal products and fisheries with 2-3 billion, rubber with 1.0 billion RM and other minor fruit export like papaya, star-fruit, pineapple, mango, etc. The country still imports 11-12 billion RM of food products, and since local food production is 3-4 billion RM, there is a deficit of 7-8 billion RM. The Malaysian agricultural policy is to transform the agricultural sector into a modern, viable and competitive sector. Excluding the plantation sector, project implementation for the rural community will be under taken as an integrated basis (MOA approach) through agencies of the MOA like DOA, PORIM, RRIM, MARDI, DID, FAMA, PPK, RISDA and Fisheries/Veterinary Department. Malaysian agricultural policy makers will take cognizance of the importance of sustainable agriculture through conserving our agricultural resources and producing not only safe but also high quality agricultural products. To ensure that our products are safe we have implemented the Malaysia Accreditation scheme from January, 2002. This is based on EUREP-GAP and Cordeaux standard.

Mr. Vele Kagena -- "Country policy profile for Papua New Guinea forwards sustainable agriculture development"

The agriculture sector remains the main stay of PNG' economy especially the we rural economy. While significant pockets of pure subsistence agriculture do exist, the livelihood of the majority of the rural population is supported by semi-subsistence agriculture which comprises traditional subsistence gardens that provide the basic needs for the family and small-scale commercial agriculture that provides the family with cash income. In terms of its direct impacts at the livelihoods of the majority of Pupua New Guinea, semi-subsistence agriculture is the most important economic sector. It sustains the livelihood of the 85% of the population of the 5.1million people residing in rural areas and engaged in a mixture of cash cropping and subsistence agriculture. About 983,767 households are engaged in food/root crops and vegetables, livestock, fishing, coffee, coconut, coco oil and rubber. Agriculture contributes about 25% to the GDP and about 29% of the population is food consumers as based on the 1996/98 survey data which is increase of 3% over the period of 1990/92 period (FAO,2000) which classified PNG an a low income deficit by FAO 1996. Poverty and rural development are critical issues being identified for policy adjustment in addressing sustainable agriculture development in the country. Theses areas are clearly reflected in the governments MTDS 2003-2007 including expansion and diversification of the sectors, poverty alleviation and food security. Some problems that contribute towards effective implementation of the policies are; lack of constitutional policy capacity within the government system, inadequate linkage and integration with various stockholders, poor agriculture extensions service, marker, information, poor resources allocation, inadequate research capacity, poor and adequate skilled manpower, poor infrastructure and poor access to credit has hampered the progress of agriculture and rural development. Existing policies and strategies developed in addressing sustainable agriculture development include: Medium team Development Strategy 2003-2007 developed by the Department of National Planning and Rural Development (DNP & RD); 1996 Agriculture white paper, Draft rice policy 2003, National Agriculture Development Strategy 2002-2012, DAL Corporate Plan 1999, and the Draft Agriculture Development Policy 2003. Despite comprehensive work in policy formulation there has been limited action taken at the implementation of policies and strategies that would enhance agriculture, food security and rural development. The main line departments highly concerned by agriculture, food security and rural development are Department of Agriculture and Livestock (DAL), Department of Health (DOH), Department of National Planning and Rural Development (DNP & RD), Department of Education (DOE), Department of Environment and Conservation (DEC) and Department of Home Affairs (DHA) and the 19

Provincial Governments of PNG.. A better multi-stockholder coordination of rural development support activities at national, regional and local is required to identify gaps to promote and support sustainable agriculture development in PNG.

Panel Discussion

In recent years, paddy farming becomes very closely located with Urban Areas. It has been argued that paddy farming consumes much of the available freshwater and is always referred to as being highly inefficient use of freshwater. Population growth and modernization is associated with increasing demand for freshwater. And being to, the threat to sustainable agriculture is the increasing conflict in the water use between urban and agriculture.

Monday, 18 November 2003

Session 3: Cropping System

Dr. Shan-Ney Huang -- "Multiple Cropping as a Strategy in Sustainable Soil Management"

considering use multiple cropping as actual alternatives we need to understand thoroughly the biological and agronomic basis responsible for the observed response, as well as the advantages and disadvantages to their use. The disadvantages of multiple cropping systems are 1).competition between plants for light, soil nutrients and water, 2).it is difficult to harvest one crop without damage the other, mechanize and incorporate a fallow period in or into the systems 3).possible over-extraction and loss of nutrients and allelopathic influence between different crop plants.

Panel Discussion

Monocropping of rice is very unique in that it is not causing soil sickness problem. Soil sickness may be caused by plant pathogens or toxic substances. Most microorganisms including plant pathogens can not survive the long-term submerging conditions. Submerging in water also favors the degradation of toxic substances.

Recognizing the fact that multiple cropping should be one of the best strategies in soil management on a sustainable way, not many cases of multiple

cropping have been documented. Paddy rice could be grown twice a year continually for hundred and hundred years without causing significant damages to soil and paddy. Is there any justification for the need of multiple cropping.

Session 4: Soil Fertility Management and Recycling of Agricultural Wastes

Dr. Morihiro Maeda -- "Nitrate Contamination of Groundwater and Soil Management"

This paper focuses on the relation between nitrogen (N) fertilization and groundwater contamination. First of all, the utilization efficiency of N fertilizers for outdoor cultivation of vegetables is usually 50% or less in Japan, and then he (the speaker) described a NO_3 leaching study in a Japanese Andisol treated with three types of N fertilizers in addition to a control (swine compost, coated urea, ammonium N, or no fertilizer) for 7 years. Sweet corn (Zea mays L.) was grown in summer, followed by Chinese cabbage (Brassica rapa L. var. amplexicaulis) or cabbage (Brassica oleracea L. var. capitata) in autumn each year. The results indicate that, under the Asian monsoon, excessive N from chemical fertilizers applied to Andisols can cause substantial NO_3 leaching, while compost application is promising as a mean of establishing high yields and low N leaching during a few years, but would cause the same level of NO_3 leaching as in chemically fertilized plots over longer periods.

Q: What are the values of the additives used in the experiment? (Mr. Denis Hamilton)

A: The values of the additives are difficult to be evaluated in the experiments as only the same amount of nitrogen for nitrate fertilizer and coated urea was used. Also, only one type of compost was selected in the experiment. We only developed the model for assessing the nitrate contamination. (Dr. Morihiro Maeda)

Dr. Ping-Yi Yang -- "Biological Treatment Technology for Recycling Agricultural Wastes for Sustainable Agriculture and Environmental Protection"

This presentation reviewed the existing agricultural waste characteristics,

the role of biological treatment technology, and the potential integration of treatment technology. He point out the Modification and integration are the two promising components of the biological treatment technology for the achievement of the goals planned.

Q: 1.Mr.Yeo Teng Tay reported that the vegetable growing areas of Cameron Highland produced a lot of coco peat waste. What can we do to decompose this waste? (Mr. Yeo Teng Tay)

A: Mixing coco peat waste with chicken manure can help decompose the coco peat. Another alternative is to decompose it by using a fungus, *Trichoderma* sp.

Session 5: Pest Management

Dr. Wen-Hsiung Ko -- "Managing Plant Diseases without Using Pesticides in Sustainable Agriculture"

This presentation illustrated various control methods without using any pesticide. Dr. Ko highlighted that through the systematic exclusion of each possible causal factor, and the confirmation of the working hypothesis by experimentation, several kinds of disorders were found to be due to nutrient deficiency and were controlled by application of appropriate nutrients.

Q: Powdery mildew is a serious tomato disease in greenhouse. Did you ever try to use biological agent like mycoparasite to control it? (Mr. Hyun Gwan Goh)

A: I tried a hyperparasite, *Ampelomyces quesquales,* to control powdery mildew of tomato but was not very effective. Using emulsified vegetable oil is more efficient and effective.

Q: The use of non-chemical type methods to manage plant diseases can be successful. But in the case of large scale locust problem how do you manage it without using pesticides? (Dr. Yaoqi Chen)

A: The same principle can probably be applied to control insect pests. But it is hard to control when a pest population has already built up. Preventing a population build-up is better way to control. Yes , it is difficult to control pest

problem without pesticides. (Dr. W. H. Ko)

Dr. Henry H.C. Huang – "Sustainable Management of Insect-Borne Fungal Plant Diseases: A Case Study in Canada"

Three alfalfa cultivars with high levels of resistance to verticillium wilt and bacterial wilt and adapted to the Canadian prairies, have been released from the breeding program at the Lethbridge Research Centre, Alberta, Canada. These disease resistant cultivars have increased forage yield, improved hay quality by reducing weed infestations, and prolonged stand life of alfalfa. Since verticillium wilt is an insect-borne disease, effective management of insect vectors should be part of the strategy for the control of this disease. Research on control of plant diseases by insect management remains a fertile ground and thus, demands the attention of plant pathologists, entomologists and plant breeders.

Dr. Gwo-Chen Li -- "Safety Evaluation and Regulatory Control of Pesticide Residues in Chinese Taipei"

The "tolerance" level of pesticides for different crop groups is determined on the basis of: i) the acceptable daily intake value of the pesticide; ii) the average daily consumption of each crop group by the Taiwanese people; and iii) the level of pesticide residues on different crops, estimated from supervised trials. He also said that pesticide residues on vegetables and fruits are under heavy public scrutiny, fifteen workstations for pesticide residue control have been set up by the TACTRI in different localities in Taiwan, and multi-residue methods are used for the analysis of these products. Pesticide residues commonly found on vegetables have now been identified. Educational programs for farmers have been devised, based on the analytical results obtained from these workstations. Risk assessments of dietary intakes of pesticides are carried out on a continuing basis. Results have shown that the dietary intake of pesticide residues by consumers is within safe limits.

Mr. Denis Hamilton -- "Management of Pesticide Residues in Sustainable Agriculture"

Sustainable agriculture requires the maintenance of the natural resource base and the economic viability of agricultural production. The use of

pesticides may contribute to sustainability provided the pre-registration risk assessments pass the hurdles of safety for public health, the environment and trade. Post-registration monitoring should confirm the pre-registration assessment, but we should be alert for unanticipated residues or impacts. The management of agricultural and animal industries needs special attention where land has been contaminated by previous uses of organochlorine pesticides. Production systems should be organized to minimize the extraneous residues occurring in food and to reduce dietary exposure and risks to trade.

Panel Discussion

On the research of sustainable pest management, I think this must be carried out by a multidisciplinary team.

In Taiwan, pesticide registration procedure requires only two tests such as efficiency and phytotoxicity when it is newly registered. I think it is necessary to evaluate toxicity level against animals such as fishes and rats. Also, the GAP guidelines on fruits and vegetables are important.

In a situation, a major agriculture development is to take place on a virgin land where pesticide residues are very minimal. a management plan should be developed first was agreed.

In practice, crops production is dependent on pesticides after several years, and especially in some sudden and severe cases plant diseases caused by pests can't be controlled effectively without application of pesticides.

Wednesday, 19 November 2003

Session 6: Education & Extension in Sustainable Agriculture

Dr. Po-Yung Lai -- "Education and Extension Systems in the United State and Chinese Taipei"

The higher education systems in both the United States and Taiwan function similarly in teaching, research and extension. The higher education system offers not only baccalaureate degree but also post graduate Master's and Doctor of Philosophy degrees. The land-grant system in the United States was created in 1862 for research in the experiment stations under the Morrill Act and in 1914 for the extension service under the Smith-Lever Act. Agriculture-related research in Taiwan is carried out by Taiwan Agricultural Research Institute, District Agricultural Research and Extension Stations, and academic and private institutions. The extension service in Taiwan, however,

is primarily provided by District Agricultural Research and Extension Stations and farmers' associations. Despite the differences in the systems of higher education, research and extension service in the United States and Taiwan, both systems function adequately in assisting farmers in their respective country. The challenges that both systems are facing are discussed.

Q: While farmers doing their best to sustain their products, scientists, on the other hand, is singing on a different tune. Agriculture nowadays has been market-driven and technology-dictated. It must be acceptable to consumers and is defined by the quality demanded by the market. Is there a way out for the farmer living in these contrasting environments? (Dr. Concepcion)

A: Agriculture is facing tough time both in the United States and Taiwan as it makes up less than 2% of the GNP. This leads to the misconception that we do not need agriculture. Therefore, through education, we should work with farmers to educate the public that agriculture does a lot of good for the society and environment. We should also let farmers know we are there to help them and to let the public know that the healthy, bountiful food that they eat is what farmers produce. Consumers expect that the technologies used in producing food to be environmentally friendly and good to the health. (Dr. Po-Yung Lai)

Mr. Yi-Fong Ho -- "Sustainable Development of Agricultural water in Chinese Taipei"

This paper mainly focuses on introducing the aspects dealing with irrigation performance and management prevailed in Taiwan, and some improvements due to the recent environmental and socio-economic changes, for the purpose of sustaining use of irrigation water in Taiwan. Irrigation development is no longer merely a problem of irrigation engineering. The functions and beneficial results of paddy fields and irrigation systems on production, ecology, and livelihood should all be further investigated and evaluated. In order to incorporate with Taiwan's future long-term agricultural policy, some innovative measures for sustainable development of irrigation water in Taiwan should be implemented.

Dr. Chong-Ho Wang -- "Soil Fertility Management for Sustainable Agriculture in Chinese Taipei"

Of the major fertility management practices for wet rice, N fertilization is the

most important. Since the type of cultivar and the climate have a profound effect on crop productivity, recommendations of N rates for rice are based primarily on the variety, the region and the cropping season. Recommendations of P and K rates are based primarily on results of soil testing for available P and K in the soil. There has, however, been a significant decline in rice response to these nutrients, compared with the response observed in the past, and in consequence there has been an accumulation of available P in the soil. More research should be done on whether further applications at such high rates are really needed. It is much stressed to develop the "on-site" and quick soil diagnosis to regulate and recommend rational fertilization in vegetable fields. Particularly in intensive cropped vegetable production for environmental conservation. Leaf diagnosis and soil testing present as a guide for economic fertilization of orchards. Thus, The extension work of nutrient diagnosis in fertilizer recommendation service by leaf analysis and soil test should be strengthened and made really available to farmers.

Dr. Rogelio Concepcion -- "Sustainable agriculture development in the Philippines: revisit of tools and values of agriculture"

In the Philippines, various forms of agricultural systems have emerged because of the pressures from rapid increase in population and accompanying urbanization. It was clarified that agriculture to be sustainable must take into account the role of the market and the overall economic development of the country, Agriculture development and technology applications must not be static and must continuously harmonize with the ever changing market and economic situations. The Philippines has passed a Law on Agricultural Modernization which protect agricultural lands from irrational conversion. Three good agricultural practices to address food security and water needs for agriculture were discussed. This includes the promotion of Hybrid Rice, the use of Organic based balance fertilization technology and the implementation of Community-base Rainwater Harvesting Technology. In order to provide a total picture of the role of sustainable agriculture and its contribution to national food security and environment, the concept of multi-functionality was presented. This method of valuation provides some estimate of the monetary values of the key externalities of agriculture.

Mr. Valery Popovtsev -- "Sustainable Agriculture in New Russia"

The Russian agricultural privatization program was intended to run

privately owned farms since 1991. Market-oriented economic reforms have accelerated in Russia. Today, on the transition period of Russia economic development the problematics of development of agricultural production and sustainable life-support connected to life and activity of the population of rural territories, seems urgent, very difficult and inconsistent. It's basic components include: Development of full market attitudes; The achievement of high level of efficiency in agricultural production of Russia ensuring food security; Formation of socio-economic conditions of life and activity of the rural population adequate to the modern requirements; Development of organic agriculture: Agricultural tourism; Landscape agriculture; Protection of natural resources and environment.

Dr. Tze-Chung Huang -- "Non-pesticide Methods for Controlling Plant Diseases and Insect Pests in Chinese Taipei"

In order to minimize the negative effects caused by the use of pesticides, plant protection institutions have started intensive researches and extensions of non-pesticide methods since early 1970's. With the efforts over the past few years, we have promoted awareness of non-pesticide control, and brought many techniques into extensive application resulting in satisfactory outcomes.

In recent years, some exotic predatory mites have been introduced into Taiwan and tested for their effectiveness of controlling spider mites, and exotic parasitic wasps were introduced to be tested for controlling silver leaf white fly that invaded Taiwan in 1989. Techniques for mass rearing of the promising natural enemies have been invented or improved that will make the extensive application of the biocontrol agents possible. Other non-pesticide methods that have been carried out in Taiwan include using sex pheromones to control many insect pests use of methyl eugenol and cuelure mixed with insecticides to annihilate male oriental fruit fly and melon-fly. With regard to plant diseases, we have gained remarkable achievements. For example, controlling soil-borne diseases of high-value crops by steam sterilization, producing pathogen-free propagating materials to prevent systemic diseases, especially that are caused by viruses, control of plant diseases with antagonistic microorganisms. Moreover, the use of resistant rootstocks for the control of soil-borne diseases also resulted in a success. Several projects supported by National Science Council or Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ), Council of Agriculture, aiming at developing transgenic plants resistant to different kinds of diseases are in progress.

Mr. Hyun Gwan Goh -- "Status of Greenhouse Insect Pest Biological Control in Korea"

Korea has a large greenhouse areas (82,544 ha) and an insect pest population are also high compared with greenhouses in the western countries. In strawberries and tomatoes, pests are not much of concern since biological control can be easily employed using only several natural enemies. The biological control systems have been developed for insect pests of these crops in Korea through RDA. RDA has developed several mass rearing techniques including rearing of predatory mite, *Phytoseiulus persimilis*. This technique has been transferred and disseminated to Agricultural Extension Centers and three natural enemy companies. This year *Phytoseiulus persimilis* was used to control two-spotted spider mite on commercial strawberry planted in about 215 ha, banker plants for aphids control were used on commercial leaf vegetable planted in 34 ha, and *E. formosa* was used on tomato planted in 1 ha.

Ms. María del Pilar -- "Quality Management and Good Agricultural Practices"

The peruvian agrarian vision is defined as following "Organized farmers, competitive, profitable, social, economic and environmental sustainable, in a democratic context with equality of opportunities", according to the official governmental documents. This objective revisit great importance because near 50% of the active population depends on the agrarian sector and because our country is privileged in resources and biodiversity. For this, is a social and economies imperative to work harder, hand to hand with the private enterprise, the civil sector and the international cooperation to achieve the objectives. Actually, the Minity of Agriculture is seriously commitment to improve its role: normative, orientator, promoter and regulator.

This is a great challenge for developing counties as Peru, characterized for the concentration of basic science and to be scarce and inefficient also, fragmented sector, great gaps between high and short farmer, low conscious to preserve our resources under the poverty jurisdiction.

This situation creates a vicious circle, reinforcing the poverty in the rural areas. In Peru, after a lot of experiences, we noticed that the unique way to assure the foods are enhancing farmer's capabilities in technical, management and organization aspects, so the farmers lead their doctrine, becoming in an active subjects of these process. In this sense, in the Ministry of Agriculture we proposed "Management Quality and Good Agricultural

Practices-PromBPA". We adopted the EurePGAP Protocol as a strategy because its development proposal is integral: healthy for consumers, occupational safety in harmony with the environment. Also, is easy to understand for the farmers. We are conscious that it will be a long process, we face enormous internal and external obstacles, but we are convinced that we are in the right way.

The 3rd APEC Workshop on Sustainable Agricultural Development

Participants & working group

The 3rd APEC Workshop on Sustainable Agricultural Development
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